TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

ANTTI KESKI-KOUKKARI

ARCHITECTURE OF SMART GRID TESTING PLATFORM AND INTEGRATION OF MULTIPOWER LABORATORY

Master of Science Thesis

Examiner: prof. Pertti Järventausta
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ABSTRACT

ANTTI KESKI-KOUKKARI: Architecture of Smart Grid Testing Platform and Integration of MultiPower Laboratory
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Traditional electrical grids are shifting towards Smart Grids that could deliver electricity in sustainable, economic and secure way. Simultaneously, characteristics of electrical grids are becoming much more complex that require development of several Smart Grid functionalities. This thesis studies architecture modeling of Smart Grid Testing Platform (SGTP) and integration of MultiPower laboratory. The architecture was defined in collaboration with research project team in a project called "Integrated business platform of distributed energy resources" (HEILA). Furthermore, the main goals are to produce an architecture model, which promotes specific Smart Grid related use cases, and interconnect the MultiPower laboratory with the platform.

This thesis is divided into two parts. Firstly, background, challenges with Smart Grids, the HEILA project and MultiPower laboratory are introduced. Then, Smart Grid Architecture Model (SGAM) Framework, tools and related architecture definitions in different projects are studied. In addition, information models defined by IEC 61850 standard and Common Information Model (CIM), Smart API, HyperText Transfer Protocol (HTTP) and MQ Telemetry Transport (MQTT) protocols are studied because of their central role in the architecture model and integration. Secondly, results are presented with descriptions of the architecture model and integration process.

The architecture model presents how different actors cooperate in order to offer and use flexibility related services on distribution level. The architecture model increases level of details, adds functionalities and changes some of the protocols used when compared to the related architectures. Additionally, self-descriptive and more flexible messaging are introduced as messages contain semantic information and they are not bound to any specific format. The function positioning with two-way communications promotes decentralized data acquisition and control. Generally, that may ease market integration, privacy, autonomy and scalability issues. As a result, the architecture may promote development and utilization of different kind of flexibility related services and products. However, information objects should be added to the standard mapping on information layer of the model since it would increase level of details. The integration was successful since monitoring and controlling of the MultiPower equipment is possible with current version of the SGTP as tests demonstrate. Technical requirements in the use cases were fulfilled.

In future research work in the HEILA project message encryption, validation and CIM utilization should be considered. Moreover, Energy Management System (EMS) and equipment that is more suitable for routine testing should be considered for the MultiPower.

TIIVISTELMÄ

ANTTI KESKI-KOUKKARI: Älykkään sähköverkon testausalustan arkkitehtuuri ja MultiPower laboratorion integraatio
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Avainsanat: älykäs sähköverkko, arkkitehtuurimalli, joustavuus, integraatio

Perinteiset sähköverkot ovat muuntumassa älykkäiksi sähköverkoiksi, jotka voivat toimittaa sähköä kestävällä, taloudellisella ja turvallisella tavalla. Samanaikaisesti sähköverkon ominaisuudet muuttuvat paljon monimutkaisemmiksi, mikä vaatii älykkäiden sähköverkkojen toiminnollisuuksien kehittämistä. Tässä työssä tutkitaan älykkään sähköverkon testausalustan arkkitehtuurin mallintamista ja MultiPower -laboratorion integrointia. Arkkitehtuuri määritettiin yhteistyössä tutkimusryhmän kanssa Hajautettujen Energiaresurssien Integroitu Liiketoiminta-alusta (HEILA) -projektissa. Päätavoitteina on tuottaa arkkitehtuurimalli, joka tukee tiettyjä HEILA -projektissa määriteltyjä älykkään sähköverkon käyttötapauksia, ja yhdistää MultiPower -laboratorio osaksi testausalustaa.

Työ jakaantuu kahteen osaan. Ensiksi esitellään älykkään sähköverkon taustaa ja haasteita, HEILA -projekti ja MultiPower -laboratorio. Lisäksi käsitellään älykkään sähköverkon arkkitehtuurin mallinnusta, työkaluja ja työhön liittyviä arkkitehtuuri määrittelyjä eri projekteista. Tarkastelun kohteena ovat myös informaatiomallit, jotka IEC 61850 standardi ja Common Information Model (CIM) määrittelevät, sekä Smart API, HyperText Transfer Protocol (HTTP) ja MQ Telemetry Transport (MQTT) protokollat, koska ne ovat keskeisessä asemassa määritellyssä arkkitehtuurissa ja integraatiossa. Toisessa osuudessa esitellään tulokset kuvailemalla arkkitehtuurimalli ja integraatioprosessi.

Arkkitehtuurimalli esittää miten eri toimijat toimivat yhteistyössä hyödyntääkseen erilaisia joustavuuteen liittyviä palveluita jakeluverkkotasolla. Arkkitehtuurimalli kasvattaa yksityiskohtien määrää, lisää toiminnollisuuksia ja käyttää osin eri tiedonsiirtoprotokollia, kun verrataan työhön liittyviin arkkitehtuurikuvauksiin eri projekteissa. Erona on myös itseään kuvailevat viestit ja joustavampi kommunikointi. Viestit eri toimijoiden välillä pääosin sisältävät semanttista dataa, eivätkä ne ole sidottu tiettyyn formaattiin. Arkkitehtuurissa toiminnollisuuksien sijoittelu ja kaksisuuntainen kommunikaatio tukevat hajautettua tiedonkeruuta ja ohjausta. Yleisesti ne voivat auttaa markkina, yksityisyys, riippumattomuus ja skaalautuvuus ongelmissa. Siten arkkitehtuuri voi edistää joustavuuden käyttöä ja siihen liittyvien palveluiden kehitystä. Arkkitehtuurimalliin tulisi kuitenkin lisätä informaatio-objektit standardien kuvauksen yhteyteen informaatiokerrokselle, koska se lisäisi mallin tarkkuutta. Integraatio oli onnistunut, koska MultiPower laboratorion laitteita pystytään valvomaan ja ohjaamaan testausalustan nykyisen version avulla, kuten testit osoittivat. Myös käyttötapausten tekniset vaatimukset täyttyivät.

Viestien salausta, validointia ja CIM:n hyödyntämistä tulisi jatkossa harkita HEILA -projektissa. MultiPoweriin suositellaan energianhallintajärjestelmää ja laitteita, jotka soveltuvat paremmin rutiininomaiseen testaukseen.

PREFACE

This thesis was written for VTT Technical Research Centre of Finland as member of Power Systems and Renewables team. Furthermore, this thesis was written as part of "Integrated business platform of distributed energy resources" research project.

I would like to express my gratitude to my thesis supervisor D.Sc. Anna Kulmala for her encouragement, trust, guidance and support thorough this work. I am very thankful for Petra Raussi sharing her knowledge on MultiPower laboratory and for extensive support. I would like to thank Pyry Lehtimäki for sharing his knowledge on Smart API. I would like to thank research project team for cooperation, constructive discussions and commenting. I would also like to thank prof. Pertti Järventausta for examining this thesis and Geert-Jan Bluemink for this opportunity.

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Antti Keski-Koukkari

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

ACT	ACTuator
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
AMS	Aggregator Management System
API	Application Program Interface
ASDU	Application Service Data Unit
BRP	Balance Responsible Party
BUC	Business Use Case
CA	Commercial Aggregator
CASDU	Common Address of Application Service Data Unit
CDC	Common Data Class
CDPSM	Common Distribution Power System Model
CEMS	Customer Energy Management System
CIM	Common Information Model
CRP	Conditional Re-Profiling
DER	Distributed Energy Resource
DMS	Distribution Management System
DNS	Domain Name System
DPC	Controllable Double Point
DREAM	Distributed Renewable resources Exploitation in electric grids trough Advanced heterarchial Management
DSL	Domain Specific Language
DSO	Distribution System Operator
EM	Electronic Meter
EMS	Energy Management System
EPRI	Electric Power Research Institute
EU	European Union
EV	Electric Vehicle
FLISR	Fault Location Isolation and Service Restoration
FMO	Flexibility Market Operator
FMP	Flexibility Market Platform
GPS	Global Positioning System
HLUC	High-Level Use Case
HMI	Human Machine Interface
HTTP	HyperText Transfer Protocol
ICT	Information and Communication Technology
IDE	Integrated Development Environment
IED	Intelligent Electronic Device
IGBT	Insulated Gate Bipolar Transistor
IO	Information Object
IOA	Information Object Address
IoT	Internet of Things
IP	Internet Protocol
IRI	Internationalized Resource Identifier
I2ND	Interface to Network and Devices
LAN	Local Area Network
LD	Logical Device
LN	Logical Node

LUT	Lappeenranta University of Technology
LV	Low Voltage
MDC	Meter Data Contentrator
MGCC	MicroGrid Central Controller
MGMS	MicroGrid Management System
MMS	Manufacturing Message Specification
MO	Microgrid Operator
MQTT	MQ Telemetry Transport
MV	Medium Voltage
NCC	Network Control Centre
NTP	Network Time Protocol
OWL	Web Ontology Language
PMU	Phasor Measurement Unit
PQM	Power Quality Meter
PUC	Primary Use Case
PV	Photovoltaic
QoS	Quality of Service
QUDT	Quantities, Units, Dimensions, and Types
QVT	Query/View/Transformation
RDBMS	Relational DataBase Management System
RDF	Resource Description Language
RES	Renewable Energy Source
RTDB	Real-Time DataBase
RTU	Remote Terminal Unit
S-RAM	SEAS Reference Architecture Model
SAB600	Station Automation Builder 600
SAU	Substation Automation Unit
SSAU	Secondary Substation Automation Unit
SCADA	Supervisory Control And Data Acquisition
SCL	System Configuration description Language
SCD	SEAS Core Domain
SDK	Software Development Kit
SDO	Standard Development Organization
SEAS	Smart Energy Aware Systems
SENS	SENSor
SFD	SEAS Field Domain
SG-CG	Smart Grid Coordination Group
SGAM	Smart Grid Architecture Model
SGIS	Smart Grid Information Security
SGTP	Smart Grid Testing Platform
SNTP	Simple Network Time Protocol
SPP	Service Provider Platform
TLS	Transport Layer Security
TSO	Transmission System Operator
TUT	Tampere University of Technology
UML	Unified Modeling Language
URI	Uniform Resource Identifiers
VTT	VTT Technical Research Centre of Finland
XML	eXtensible Markup Language

1. INTRODUCTION

1.1 Background

Interest towards Smart Grid and its functionalities continues growing [1] as share of Renewable Energy Sources (RES) keeps increasing globally [2] and in European Union (EU) [3]. Policies and strategies vary globally and countries outline visions to deploy the Smart Grid [1][4], which could deliver electricity in sustainable, economic and secure way [1]. Furthermore, ecosystems (e.g. [5]), frameworks (e.g. [6]) and projects (e.g. [7][8][9][10][11][12]) actively explore challenges and opportunities with the Smart Grid and devices connected to it. Nevertheless, challenge of integrating RES fully into power system and making grid smart remains unfinished [1][13]. Figure 1 and Table 1 present alteration in characteristics when shifting from Traditional to the Smart Grid.

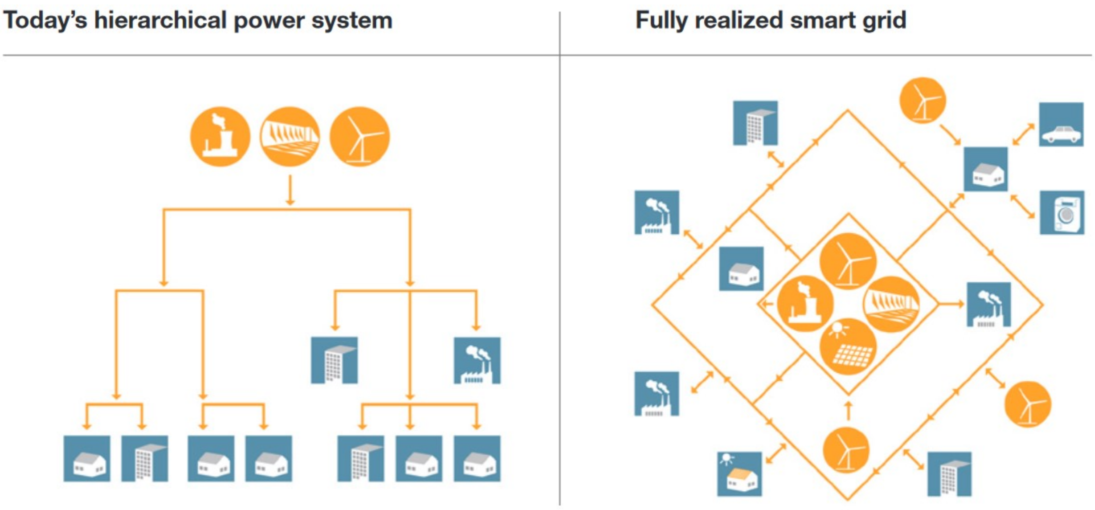


Figure 1. Shift from Traditional to Smart Grid [14].

Numerous functionalities of the Smart Grid are widely studied and multiple issues and challenges, for example, interoperability, control [1] and context-awareness [15] in the Smart Grid have clear potential for improvement. Interoperability is essential when designing and implementing architecture with existing equipment [1]. Furthermore, optimal scheduling of energy sources, power transfer maximization and real and reactive power control, to name but a few, underline necessity of intelligent control. Additionally, wide use of sensors and use of time- and location-aware information direct to context-awareness and semantic data models, for example, Common Information Model (CIM) in case of the Smart Grid [15].

Table 1. Characteristics of Traditional and Smart Grid [16] [1].

Traditional Grid	**Smart Grid**
Mechanization One-way communication	Digitization Two-way real-time communication
Centralized power generation	Distributed power generation
Radial Network Less data involved	Dispersed Network Large volumes of data involved
Small number of sensors	Many sensors and monitors
Less or no automatic monitoring	Great automatic monitoring
Manual control and recovery	Automatic control and recovery
Less security and privacy concerns	Prone to security and privacy issues
Human attention to system disruptions Simultaneous production and consumption of energy / electricity Limited control Slow response to emergencies	Adaptive protection Use of storage systems Extensive control system Fast response to emergencies
Fewer use choices	Vast user choices

This thesis is written for VTT Technical Research Centre of Finland (VTT) as part of research project called “Integrated business platform of distributed energy resources” (HEILA). The research project aims to connect diverse laboratories and pilots into an integrated energy system through Information and Communication Technology (ICT) to host various potential Smart Grid applications, which intend to incorporate Distributed Energy Resources (DERs) into novel business models of energy systems [17].

1.2 Scope and research problem

Generally, scope of this thesis is limited to Smart Grid and Distributed Energy Resource (DER) environments with focus on interconnecting VTT MultiPower laboratory environment with Smart Grid Testing Platform (SGTP). The SGTP is developed during the HEILA research project and it includes merging diverse pilots and laboratories into an integrated energy system by means of ICT [17].

The main challenges of this thesis are analyzing and visualizing specific Smart Grid use cases (see Appendix 1 and 2) in order to produce an architecture model and integrating VTT MultiPower laboratory with the SGTP. The architecture is defined in collaboration with the research project team and the architecture model is produced with specific software as part of this thesis. However, the architecture model proposed in this thesis has to be feasible in general with other use cases too.

The integration consists of implementing interfaces 1-3, which Figure 2 presents, for external (e.g. client-server) and internal (database) connections. Different parts of the SGTP are used as they are at present and their further development is out of scope of this thesis, generally. This thesis covers detailed use cases of Microgrid Monitoring and Distribution System Operator (DSO) Flexibility and provides answers for the following questions:

- What business cases, functions, information models, protocols and components the use cases have on layers of the Smart Grid Architecture Model (SGAM)?
  - What connections there are within interoperability layers of the SGAM?
  - What connections there are between interoperability layers of the SGAM?
  - How different parts of described system are located in zones and domains?
  - What differences there are when compared to related architectures?

- How does the interconnection between different sites operate?
  - What kind of components the SGTP has?
  - What software components the MultiPower laboratory equipment has?
  - What practical problems there are when interconnecting the MultiPower with the SGTP?
  - How does the connection operate?
  - What are the transfer times in different parts of tested system?

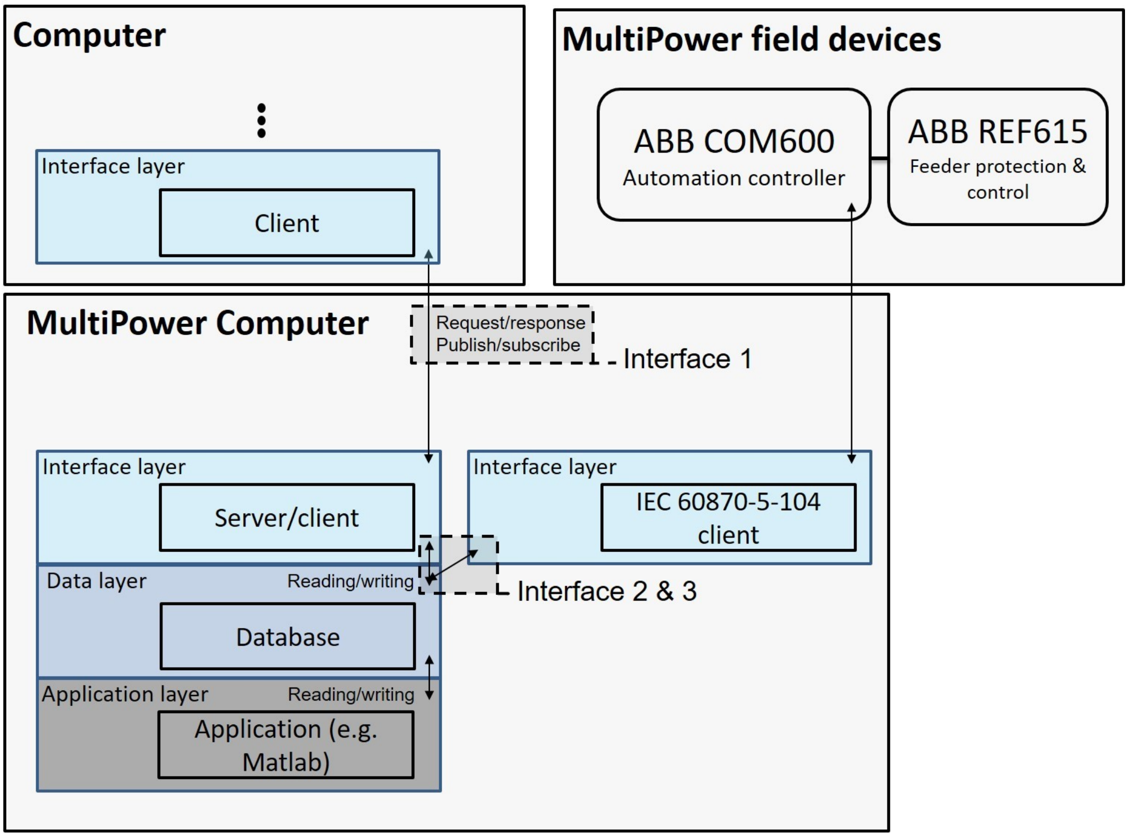


Figure 2. Scope for integration task.

1.3 Methodology

First part of this thesis is produced by utilizing specific methodology, which is introduced in paragraph 2.1, developed during the HEILA project in order to propose an architecture model that promotes specific use cases. Then, the integration requires implementing absent technical solutions that consist of installing computer programs, programming with different programming languages and configuration of computers. Additionally, the proposed architecture is utilized for preliminary tests between the MultiPower laboratory environment and SGTP.

1.4 Structure of the thesis

This thesis is divided into 7 chapters and an introduction is provided in chapter 1. The HEILA project, VTT MultiPower laboratory environment and its equipment are introduced in second chapter. Tools for architecture modeling, the SGAM Framework and methodologies are presented in chapter 3. Additionally, related architecture definitions are covered in the third chapter. Information models, concepts and protocols that are essential in ICT architecture and connection establishment are covered in chapter 4.

First of the main results of this thesis, the architecture model, is described in chapter 5. Moreover, architecture model description defines and identifies different actors, functions, related systems and interconnections. Additionally, logical positions for system components are identified and linked to related architecture definitions. Then, connection establishment and testing with use case related results are dealt with in chapter 6. Finally, conclusions are presented in chapter 7.

2. INTRODUCTION OF HEILA PROJECT AND MULTIPOWER LABORATORY ENVIRONMENT

This section provides brief overview of the HEILA project, hardware and software elements available in VTT MultiPower laboratory facilities. Furthermore, framework and HEILA SGAM use case methodology are presented.

2.1 HEILA project

The HEILA research project aims to define innovative use cases to support integration of Distributed Energy Resources (DERs), active grid management and flexibility markets [17]. The research project aims to design architecture for a platform that improves visibility and controllability of DERs among different business actors, implements necessary functionalities of the use cases and demonstrates innovative Smart Grid solutions in the platform environment. Lappeenranta University of Technology (LUT), Tampere University of Technology (TUT) and VTT are research partners of the project. Moreover, Business Finland Ltd. and 13 companies fund the project. Figure 3 illustrates outlines for the HEILA project.

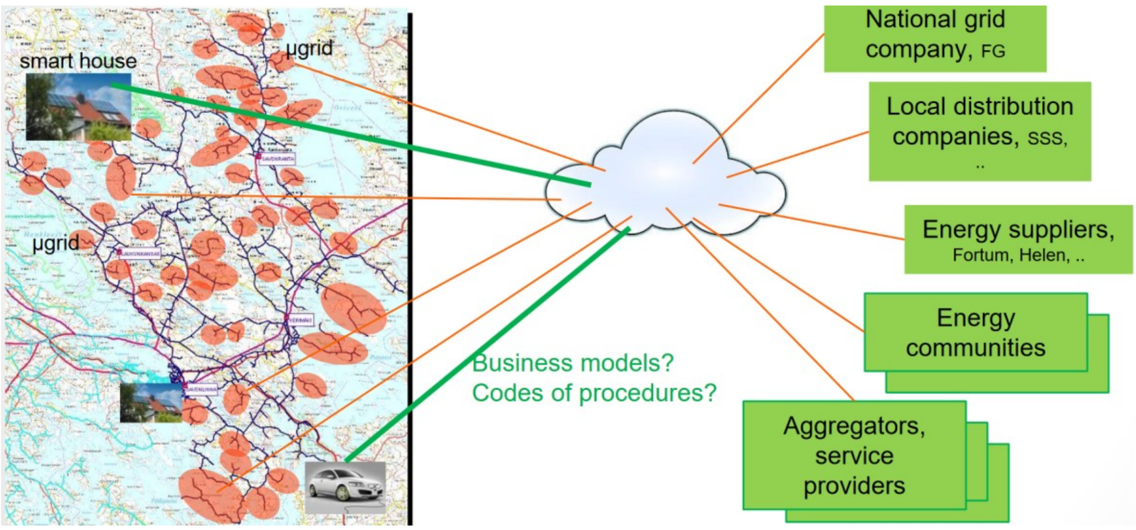


Figure 3. Outlines for the HEILA project [18]***. HEILA translates to "Integrated Business Platform of Distributed Energy Resources"*** [17]**.**

The HEILA project uses specific methodology to define architecture of the platform [17]. The methodology bases on use cases, SGAM Framework and a process that is iterative and incremental. First, use cases are gathered and extracted from different sources, which leads to general use case templates. At this point, business cases, objectives and roles of business actors, and success scenarios are identified. Then, by adding more details to the use cases, detailed use case templates are produced. The detailed use case template provides components, functionalities, exchanged information and technical requirements. In addition, use cases are visualized with Unified Modelling Language (UML) use case and sequence diagrams. Finally, detailed use cases are mapped to the SGAM and that should generate a specific architectural solution that provides functionality of the detailed use cases. Figure 4 presents the HEILA methodology.

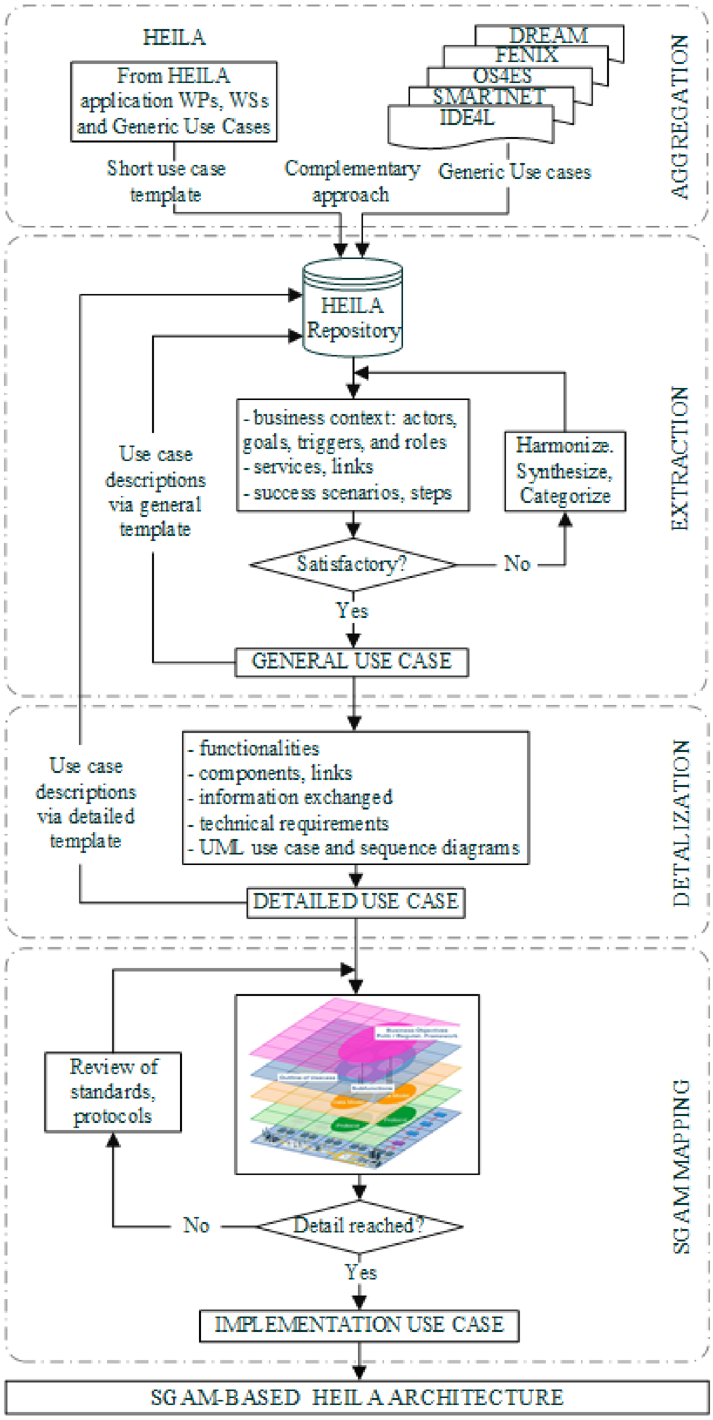


Figure 4. HEILA SGAM use case methodology [17].

As shown in the figure, steps in the HEILA methodology consist of aggregation, extraction, detalization and SGAM mapping of use cases that lead to HEILA architecture. Moreover, detailed use case templates provide input for the SGAM mapping.

2.2 MultiPower laboratory environment

The MultiPower is a national empirical research environment, which combines multiple independent testing environments [19]. Modification of grid topology is easy, so different arrangements of production and consumption are possible. The MultiPower environment offers testing capabilities for production, controlling and loading.

2.2.1 Hardware

Network of the Multipower laboratory environment consist of 400 V Low Voltage (LV) network, which connects to 20 kV Medium Voltage (MV) network via transformer [19][20]. The MultiPower splits into two separate halls with cable system connecting busbars [20]. The Wärtsilä hall contains 1,6 MVA diesel generator unit, adjustable resistive loads of 4x50 - 1700 kW and a brake dynamometer with 570 kVA motor/generator with a 755 kVA Insulated Gate Bipolar Transistor (IGBT) frequency converter. The Turbine hall contains micro-scale photovoltaic (PV) system of 750 W and a CINERGIA GE30 grid emulator rated at 30 kVA. Measurement, control and protection systems contains environmental measurements for PV system, ABB COM600 grid automation controller, four ABB REF615 feeder protection Intelligent Electronic Devices (IED), a Global Positioning System (GPS) time synchronization server utilizing the Simple Network Time Protocol (SNTP), ABB AFS677 router and communication network based on Ethernet [20][21]. Additionally, the MultiPower has a Dell PowerEdge T330 computer for configuration, communication and data transfer as Figure 5 illustrates.

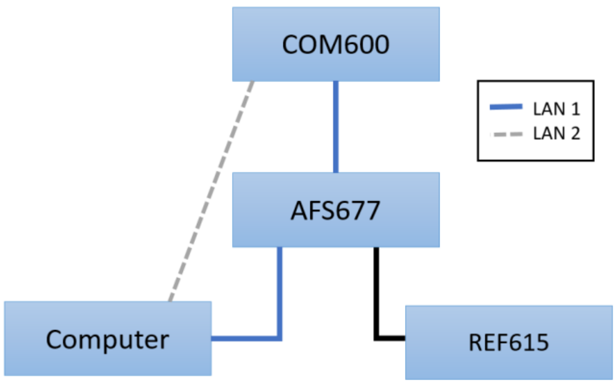


Figure 5. Communication network principle of COM600, AFS677, REF615s and computer at the MultiPower laboratory.

As shown in the figure, there is two connections, Local Area Network (LAN) 1 and LAN2, between the computer and the COM600. The LAN1 enables configuration of

COM600 for data transfer between electrical process and Network Control Centre (NCC) [21]. The NCC is part of terminology used in COM600 material. The LAN2 hosts IEC 60870-5-104 Master/Slave connection in this case.

2.2.2 Software

The COM600 provides gateway functions between protection and control IEDs [22]. Figure 6 presents conceptual view of the COM600. The COM600 uses IEC 61850-6 and -7 System Configuration description Language (SCL) and communication modeling despite of protocol that is used. Furthermore, paragraph 4.1.1 provides detailed description of the SCL and communication modeling.

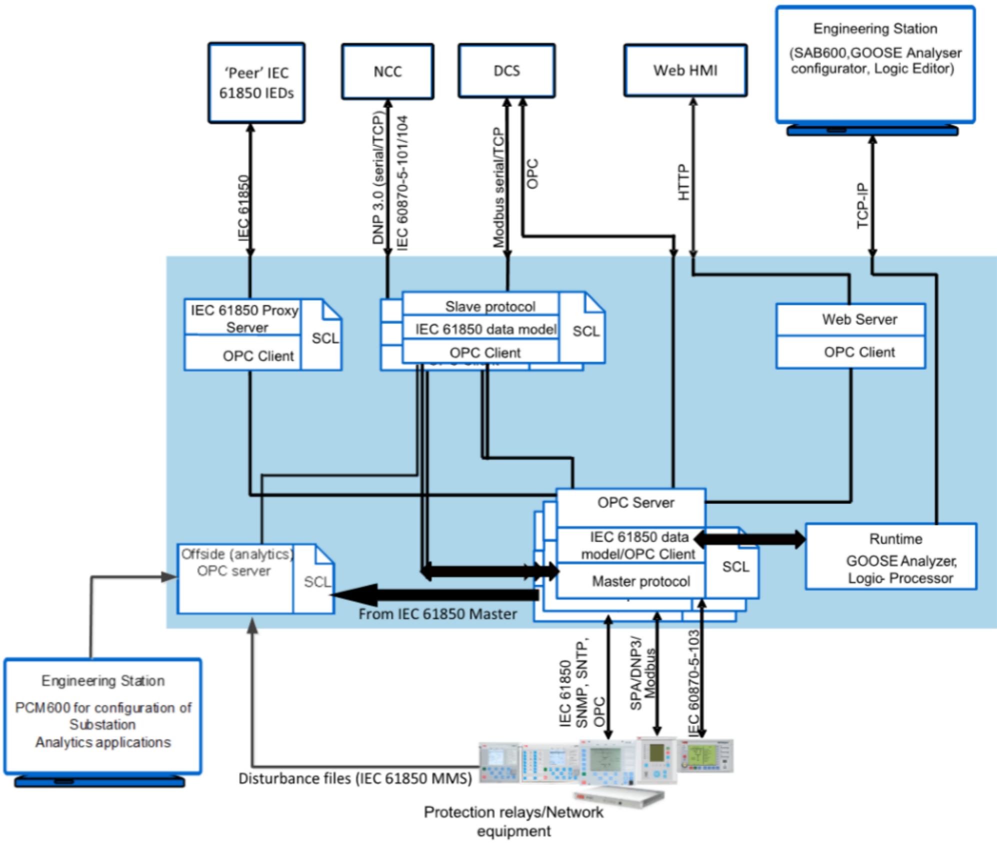


Figure 6. Conceptual view of the COM600 Gateway [22].

Usually, one OPC Client is for one NCC connection, but if there is a need for multiple NCC connections, for example with the same protocol, recommendation is to use multiple instances [22]. Optional Web Human Machine Interface (HMI) offers substation visualization, monitoring and control and it supports several browsers. Station Automation Builder 600 (SAB600) facilitates configuration and maintenance of the COM600. Moreover, SAB600 is the tool for building communication structure into COM600 and Cross-Reference function connects process data to the structure. Additionally, Logic Editor enables automation task programming. Figure 7 presents current structure built into the COM600.

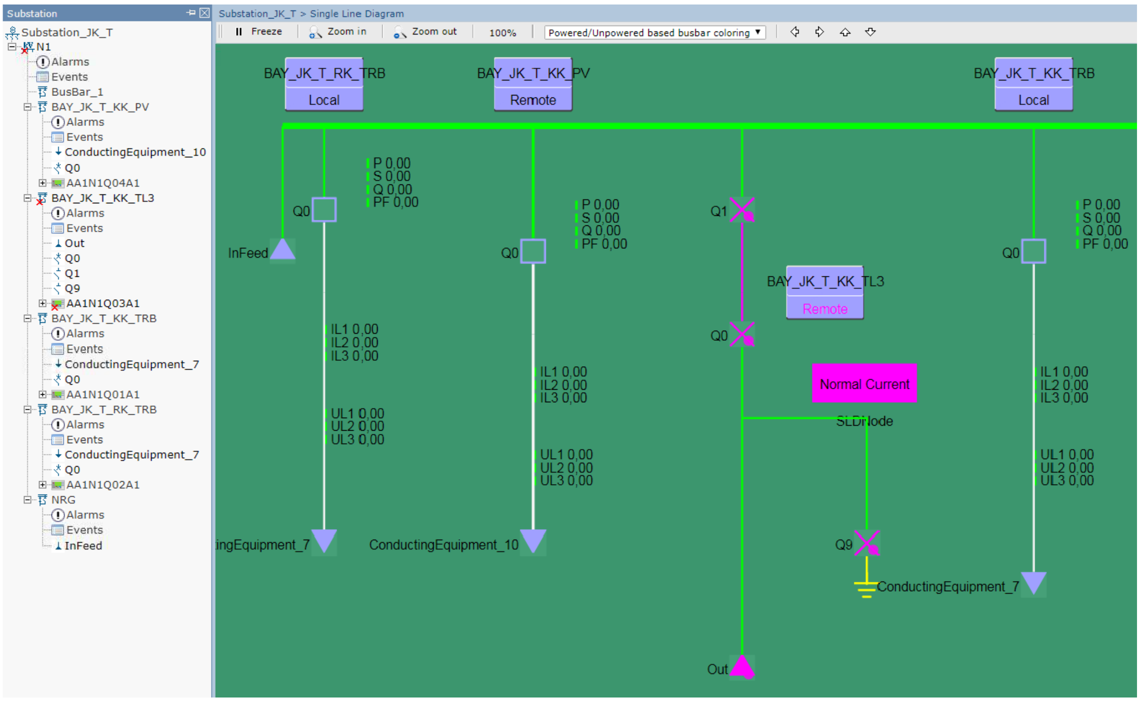


Figure 7. Current substation structure and single line diagram [21]**.**

Appendix 3 presents current data objects and signal names of JK_T_KK_TL3 REF615 that are possible to transfer between COM600 and NCC [21]. In other feeders, JK_T_RK_TRB, JK_T_KK_PV and JK_T_KK_TRB, REF615s tags are similar. Naming practice of object names in tags comply with type-system-subsystem partitioning. A dot separates hierarchical levels and an underline acts as hierarchical break. Protection stands for protection device, JK-T for the substation, KK-TL3 for the subsystem and REF615 for the physical device. Naming practice of signal names in tags follows signal type-domain-signal-sub signal partitioning. M stands for measurement type, EA for electrical AC domain, TotW for total power signal name and instMag for magnitude of an instantaneous value. The naming practice follows principles from ERIGrid project [23].

The computer in the MultiPower hosts IEC 60870-5-104 Master client, which utilizes lib60870 library from GitHub page mz-automation/lib60870 [21]. The library contains two versions and this implementation exploits lib60870.NET version written in C# programming language. Moreover, the client that is currently in use is a modification of a test client that the library provides. First results from delay tests showed that the client is able to provide measurements from REF615 to database in computer in 7-33 seconds.

The computer also hosts Real-Time Database (RTDB) called Redis [21]. This version of the Redis is available at MicrosoftArchive/redis page on GitHub. The Redis utilizes in-memory data structure store and it supports multiple data structures, such as strings, lists, sets, sorted sets and hashes, [24]. The Redis supports atomic operations running on different data structures, for example incrementing a value in a hash, and works with in-memory dataset. A feature, persistence, allows selecting if the Redis operates as in-memory cache, dumps dataset to a disk occasionally or adds each command to a log.

Another interesting Redis features are Pub/Sub and Pipelining. The Pub/Sub delivers messages to all interested (subscribed) clients and provides greater scalability [25]. However, a client which is subscribed to a topic of interest, can use only `SUBSCRIBE`, `PSUBSCRIBE`, `UNSUBSCRIBE`, `PUNSUBSCRIBE`, `PING` and `QUIT` commands. The Pipelining enables sending multiple commands to Redis server without waiting for replies and reading the replies with single step [26]. Moreover, the Pipelining improves total number of operations that a given Redis server can perform.

3. SMART GRID ARCHITECTURE MODELING

This section provides literature review about the SGAM Framework that is utilized in the HEILA project, previously defined architectures, specific use cases and tools.

3.1 Smart Grid Architecture Model Framework

This chapter presents key sections of SGAM framework. The SGAM Framework and methodology support analysis of use cases and graphical representation. This chapter also introduces useful tool for creating architecture model that supports specific use cases.

3.1.1 Introduction

Smart Grid Reference Architecture is a main result from Reference Architecture Working Group (SG-CG/RA) to EU mandate M/490 concerning the development of a Technical Reference Architecture [27]. SGAM framework and its methodology intend to ease analysis of use cases and graphical representation of use cases amongst other things.

The SGAM framework and its methodology allow both specific but also technology neutral means to present the design of smart grid use cases from architectural viewpoints [27]. The SGAM highlights interoperability aspects and consists of five interoperability layers, which represent business objectives and processes, functions, information models and exchange, communication protocols and components in an abstract way.

Aggregated interoperability categories form interoperability layers [27]. Figure 8 and Figure 9 illustrates interoperability categories and aggregation of different interoperability categories into five abstract interoperability layers.

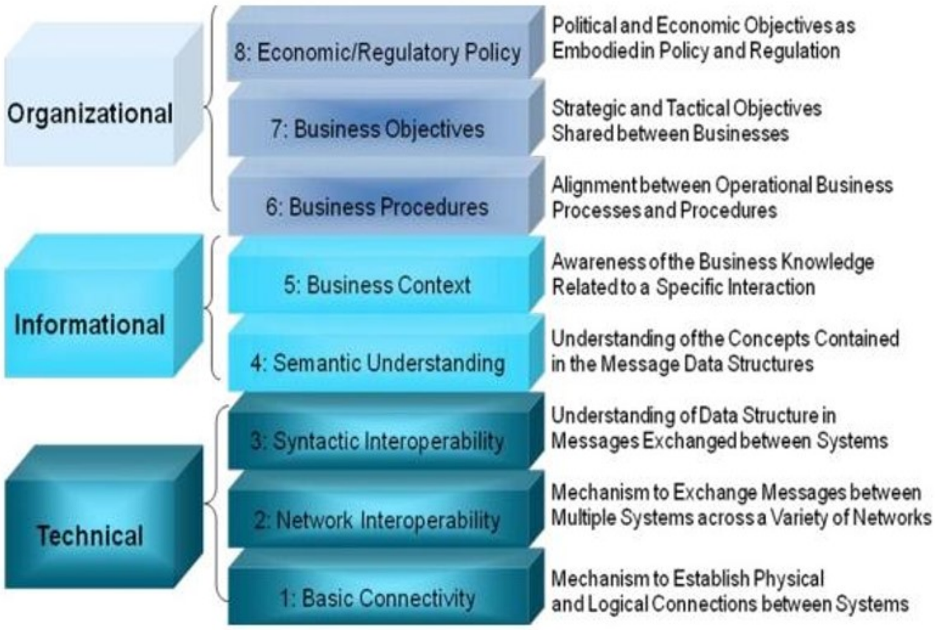


Figure 8. Interoperability categories defined by GWAC [27]**.**

Figure 9 illustrates interoperability categories that GridWise Architecture Council presented [27]. Categories are representation of accepted methodology for describing interoperability requirements for systems. Technical, informational and organizational are three drivers, which are separating categories in groups. To realize interoperable functions, standards or specifications need to cover them on all categories. In addition, agreement on cross-cutting issues such as security and privacy, resource identification and discovery is high priority when realizing interoperable functions.

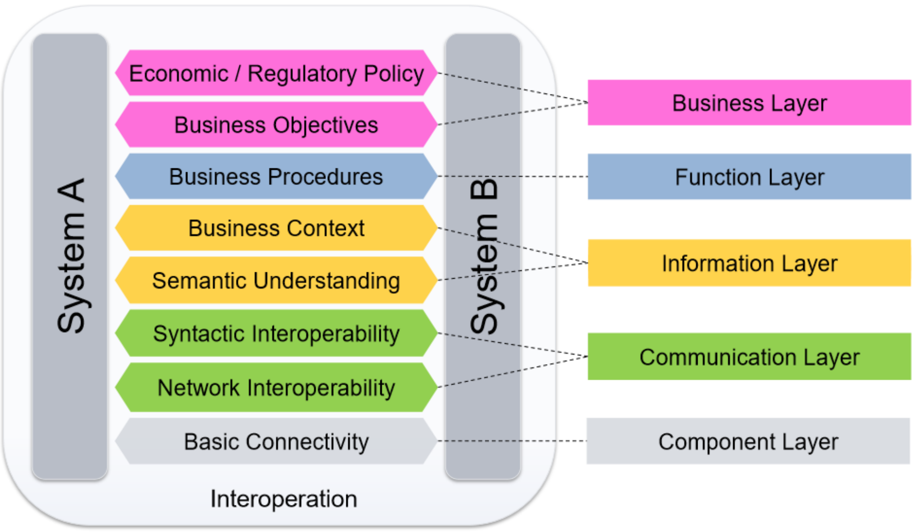


Figure 9. Interoperability categories condensed into interoperability layers [27]**.**

As shown in the figure condensing interoperability categories to layers enable clearer presentation of architecture model [27].

3.1.2 Methodology

Smart Grid Coordination Group (SG-CG) "Methodology and New Applications" Working Group (SG-CG/Meth) addresses EU mandate M/490 second phase with Smart Grid methodology and processes and its applications [28]. Phase two intents to complete and harmonize the work of phase one, if necessary. Some second phase work elements are for example, architecture models, the use case methodology and Smart Grid Information Security (SGIS) Toolbox. The methodology has two main elements, concepts and models and inserting them in specific workflow, which it relies on. Objectives of the methodology are applicability, usability and simplicity. Figure 10 and Table 2 present methodology and some key terms and definitions.

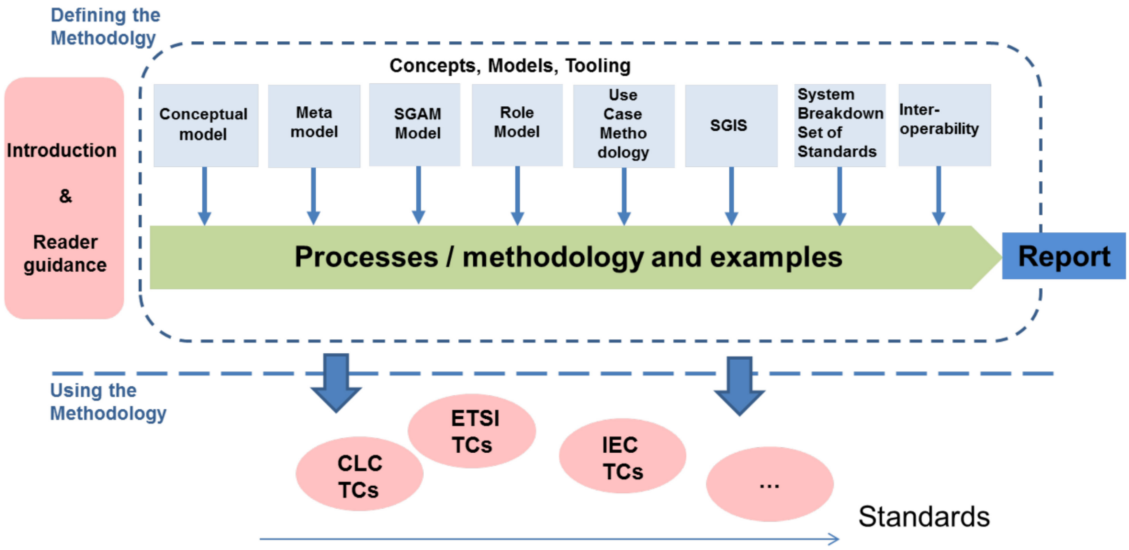


Figure 10. Elements of the methodology [28].

Use cases are a basis for further engineering, for example, in individual projects [28]. Use case methodology has several advantages. It enables information gathering about functionalities, processes, actors and requirements in organized way. In addition, it supports a common understanding between diverse stakeholder groups.

Use case template is a tool which helps to describe, compare and administer use cases [28]. The use case template covers information such as administrative information, for example, version management, and description of functions in general or detailed manner. The template also contains information about the system under discussion, scope and actor-function linking (one-step or step-by-step description). In addition, the template includes extended information for classification of use cases. Different classifications are for example, level of detail, view of the use case (business, technical), users of the use case (individual, specialized and generic use cases) and geographical relation (national, regional, international).

Table 2. Terms and definitions from [28].

Term	Definition (example)
Actor	An actor represents a party that participates in a business transaction. (Employee, Customer, Electrical vehicle, Demand-response system)
Party	Parties are legal entities, i.e. either natural persons or juridical persons. Parties can bundle different roles according to their business model. (Organizations)
Responsibility	Responsibilities define external behavior to be performed by parties. (Operate a grid, Determine the energy market price after applying technical constraints)
Role	A Role represents the intended external behavior of a party. Parties cannot share a role. Parties carry out their activities by assuming roles. Roles describe external business interactions with other parties in relation to the goal of a given business transaction. (Balance responsible party, Grid operator, Market operator)
High level use case	A use case that describes a general requirement, idea or concept independently from a specific technical realization like an architectural solution.
Primary use case	A use case that describes in detail the functionality of (a part of) a business process.
Secondary use case	An elementary use case that may be used by several other primary use cases. (Authentication, Authorization, Accounting)
Use case	Specification of a set of actions performed by a system, which yields an observable result that is, typically, of value for one or more actors or other stakeholders of the system.

Description of use cases starts from mapping High-Level Use Cases (HLUC) to SGAM domains and zones [28]. Next, the use case analyzation with SGAM is possible using different approaches. The use case and its viewpoint determines order of SGAM layers analysis. Figure 11 illustrates use case analysis sequence with SGAM.

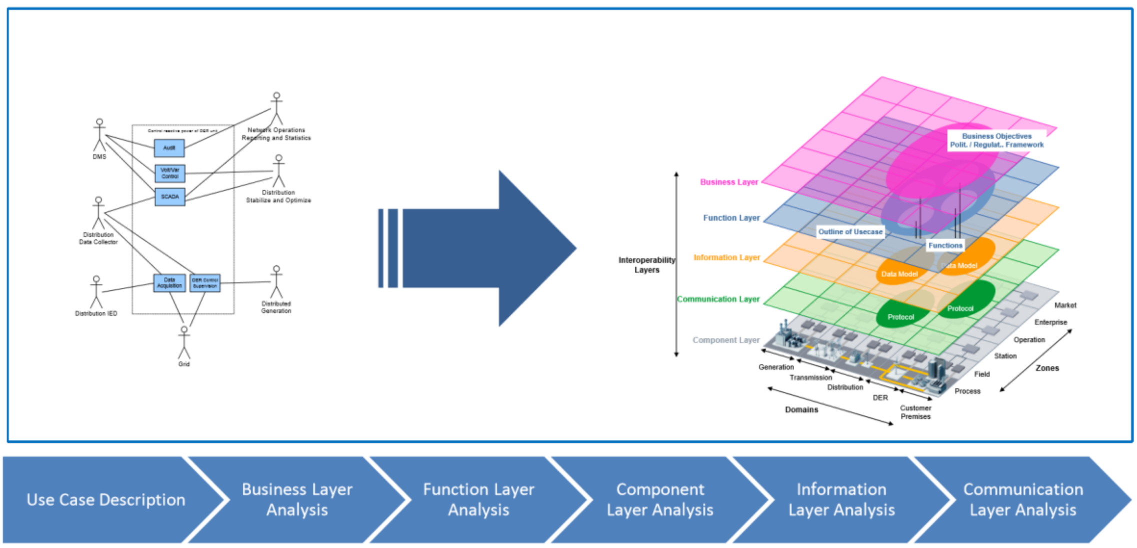


Figure 11. Use Case Analysis with SGAM [28].

Business Layer Analysis provides clear outlook on involved roles, their responsibilities and goals [28]. Lower levels of SGAM provide technical view and process starts with the Function Layer with objectives of the use case, following with Component Layer and representing position of functions on hardware. The use case information on system/device actors provide information for Component Layer forming. Information Layer analysis provides information object for the layer based on the Function and Component Layers information flows. Finally, the Communication Layer defines protocols and mechanisms for the interoperable information exchange.

Use case description and visualization depends on level of abstraction and design scope [28]. Therefore, the SGAM analysis varies accordingly. Figure 12 illustrates the analysis pattern.

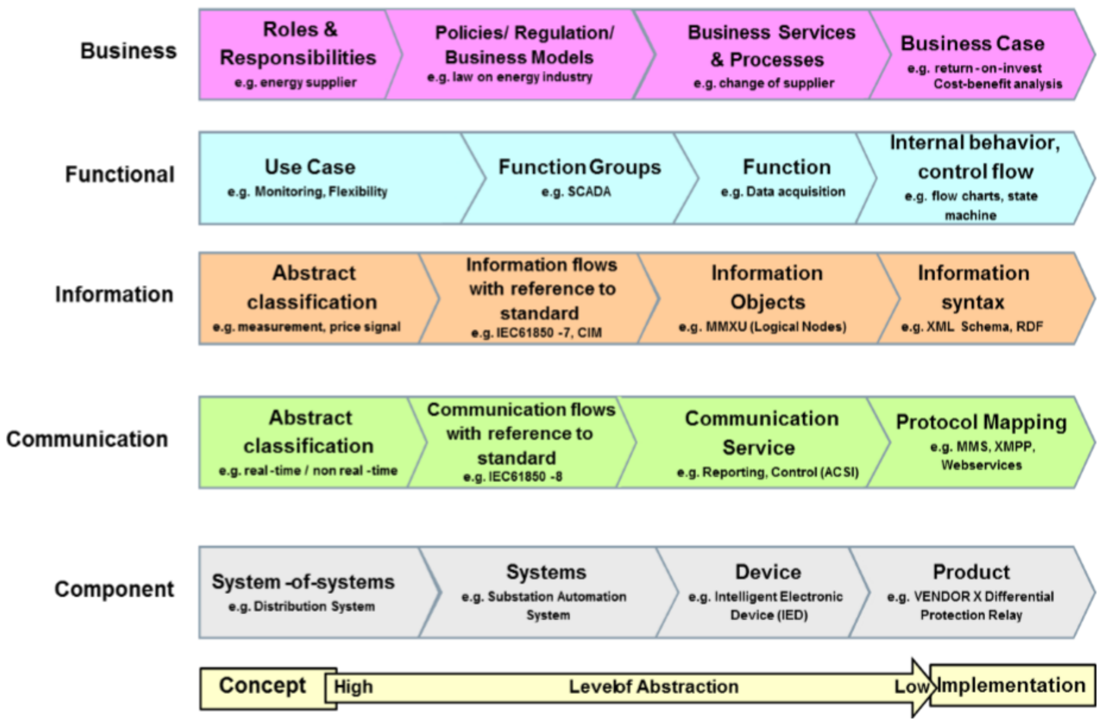


Figure 12. The SGAM analysis pattern [29].

The SGAM analysis patterns intent to instruct SGAM modeling with some steps for successive model modifications and with level of abstraction [28]. Level of abstraction turns from concept level up to a detailed level, which is essential for implementation.

3.1.3 Interoperability layers

All of the interoperability layers cover smart grid plane, which partitions in physical domains of the electrical energy conversion chain and hierarchical zones [27]. The smart grid plane facilitates examination of power system management interactions on different zones and domains. Figure 13 illustrates the smart grid plane.

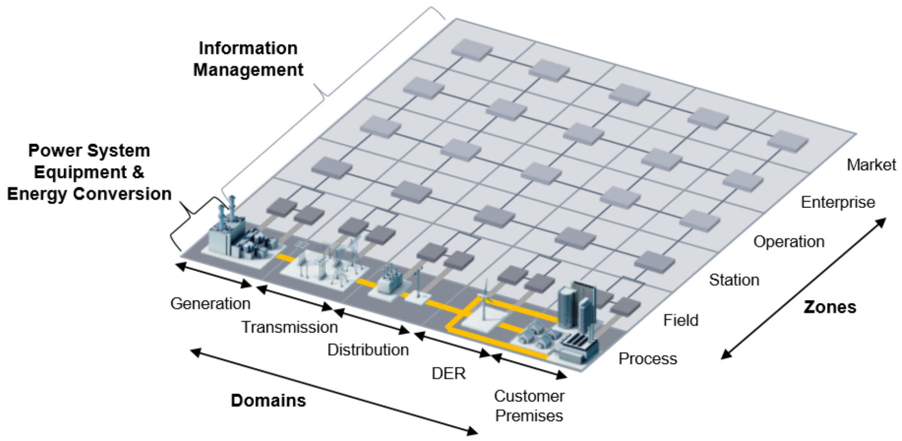


Figure 13. Smart grid plane [27].

As shown in the figure, order of domains in the smart grid plane mimics the electrical energy conversion chain [27]. Section 3.1.4 addresses domains and zones in more detail.

Business layer

The business layer of the SGAM empowers mapping of regulatory and economic (market) structures and policies, business models, business portfolios of market parties involved, thus it provides the business view on the information exchange linked to smart grids [27]. Additionally, presenting business capabilities and processes on the layer is possible. As a result, the business layer is very useful when making decisions on new business models and cases or specifying new market models.

Function layer

The functional layer of the SGAM represents functions associated to smart grid [27]. The function layer addresses functions and services with their relationships from an architectural viewpoint. The function layer separates functions from actors as well as from physical implementations in applications, systems and components. Moreover, when separating use case functionality from actors it results as functions.

Information layer

The information layer of the SGAM represents information, in abstract but formal way, that functions, services and components are exchanging [27]. The information layer includes information objects and canonical data models. Furthermore, the representation contains properties of entities, relationships and doable operations. Important matters on information layer are data management, integration concepts and required interfaces.

Communication layer

The communication layer of the SGAM describes protocols and mechanisms that components use for the information exchange [27]. The description is in the context of use cases, function or service and associated information objects or data models. The communication layer also intends to derive requirements and consider adequacy of those requirements and existing communications standards to recognize gaps.

Component layer

The component layer of the SGAM enables representation of physical components in smart grid context [27]. Moreover, the component layer contains system actors, applications, process and field level power system equipment, protection and tele-control devices, network infrastructure and computers. Therefore, basic connectivity is a key thing to describe the component layer.

Integration of these five separate interoperability layers leads to a model, which spans in three dimensions, as shown in Figure 14 [27]. The model is very useful when analyzing entities, their relationships and interoperability aspects in context of smart grid. In addition, the model supports analyzation of cross-cutting issues.

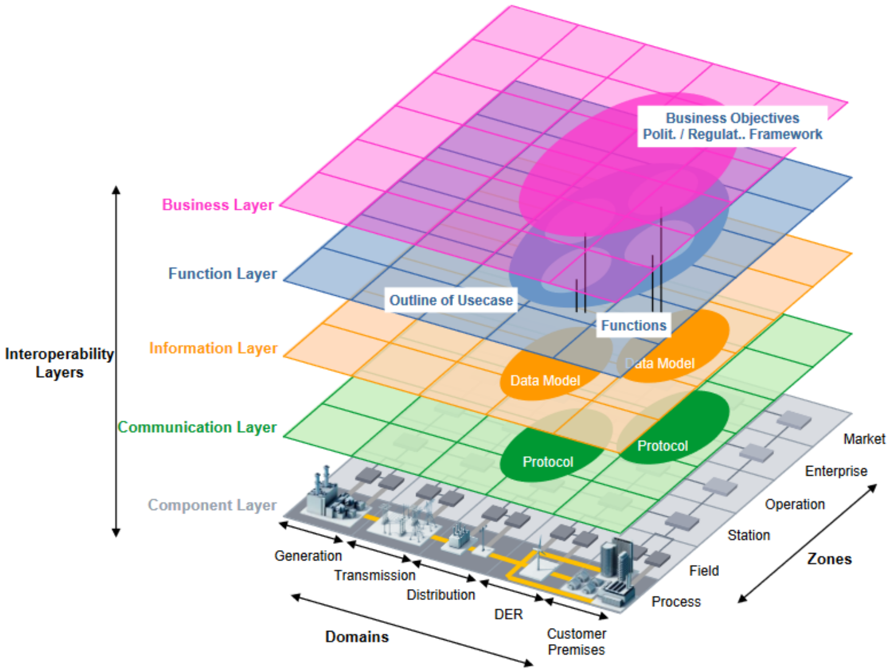


Figure 14. SGAM framework [27].

The interoperability layers represent business objectives and processes, functions, information exchange and models, communication protocols and components [27]. As a result, the model allows consideration of interoperability aspects in smart grid context.

3.1.4 Domains and Zones

The smart grid plane on SGAM divides physical domains of the electrical energy conversion chain into 5 domains and management of the electrical process to 6 hierarchical zones [27]. Table 3 and Table 4 present domain and zone descriptions.

Table 3. SGAM Domains, adapted from [27]**.**

Domain	Description
Bulk Generation	Representing generation of electrical energy in bulk quantities, such as by fossil, nuclear and hydro power plants, off-shore wind farms, large scale solar power plant (i.e. Photovoltaic, Concentrated solar power) - typically connected to the transmission system
Transmission	Representing the infrastructure and organization which transports electricity over long distances
Distribution	Representing the infrastructure and organization which distributes electricity to customers
DER	Representing distributed electrical resources directly connected to the public distribution grid, applying small-scale power generation technologies (typically in the range of 3 kW to 10 000 kW). These distributed electrical resources may be directly controlled by DSO
Customer Premises	Hosting both - end users of electricity, also producers of electricity. The premises include industrial, commercial and home facilities (e.g. chemical plant, airports, harbors, shopping centers, homes). Also generation in form of e.g. photovoltaic generation, electric vehicles storage, batteries, micro turbines… are hosted

Generally, in the SGAM organizations have actors in multiple domains and zones. Organizations may extent from process to market, for example transmission utility, or service provider located in the market zone acting with operation zone in several domains [27].

The SGAM zones express hierarchical levels of power system management (IEC62357-2011) [27]. In the SGAM zones concept of aggregation reflects to multiple aspects. For example data aggregation, which means aggregated or concentrated data from field, and spatial aggregation, which means aggregated equipment such as several bays in substation.

Table 4. SGAM zones, adapted from [27]**.**

Zone	Description
Process	Including the physical, chemical or spatial transformations of energy (electricity, solar, heat, water, wind…) and the physical equipment directly involved. (e.g. generators, transformers, circuit breakers, overhead lines, cables, electrical loads any kind of sensors and actuators which are part or directly connected to the process,..).

Field	Including equipment to protect, control and monitor the process of the power system, e.g. protection relays, bay controller, any kind of intelligent electronic devices, which acquire and use process data from the power system.
Station	Representing the areal aggregation level for field level, e.g. for data concentration, functional aggregation, substation automation, local Supervisory Control and Data Acquisition (SCADA) systems, plant supervision…
Operation	Hosting power system control operation in the respective domain, e.g. distribution management systems (DMS), energy management systems (EMS) in generation and transmission systems, microgrid management systems, virtual power plant management systems (aggregating several DER), electric vehicle fleet charging management systems.
Enterprise	Includes commercial and organizational processes, services and infrastructures for enterprises (utilities, service providers, energy traders…) e.g. asset management, logistics, work force management, staff training, customer relation management, billing and procurement.
Market	Reflecting the market operations possible along the energy conversion chain, e.g. energy trading, mass market, retail market.

3.1.5 Mapping

Analysis of use case descriptions serve as a starting point for mapping use cases to the SGAM [27]. Therefore, use case descriptions need to offer all necessary information, which includes:

- Name, scope and objective
- Use case diagram
- Actor names and types
- Preconditions, assumptions and post conditions
- Use case steps
- Exchanged information
- Functional and non-functional requirements

Mapping of actors and sub use cases, from use case information on actors, to the SGAM domains and zones initiates the mapping process [27]. The Component Layer follows with technical configuration representation with typical technical symbols. Next, the Business Layer illustrates which areas the use case is affecting. Finally, extracting functionalities from use cases results in functions and representations on the Function layer. Figure 15 and Figure 16 illustrate the example of SGAM Mapping from use case diagram to the Function Layer.

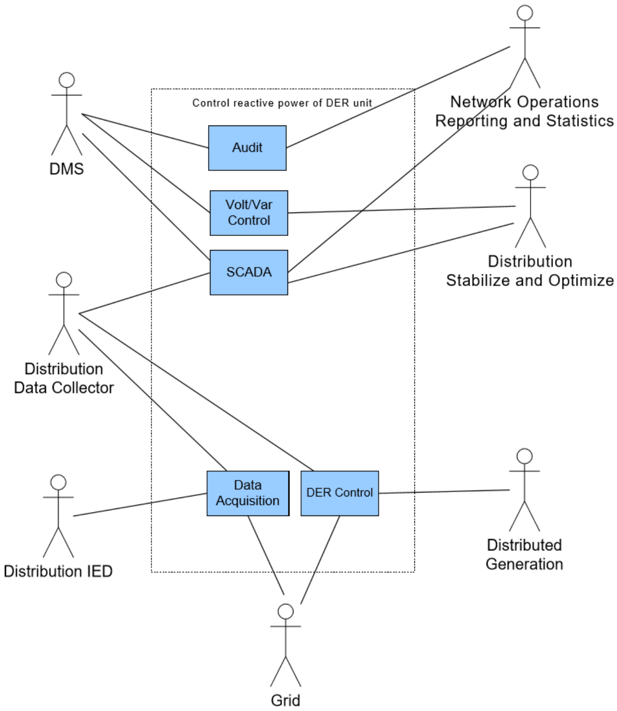
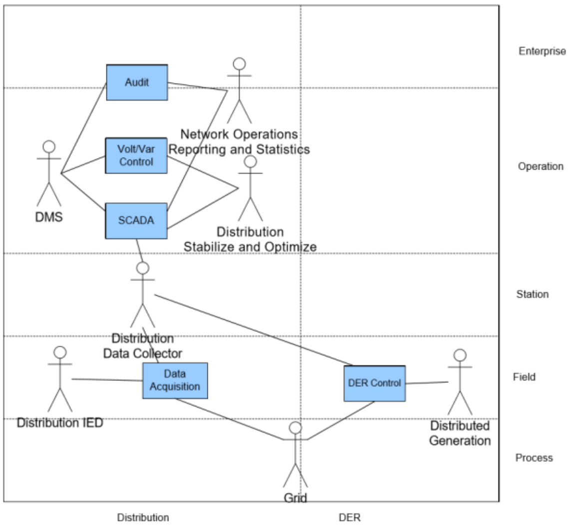
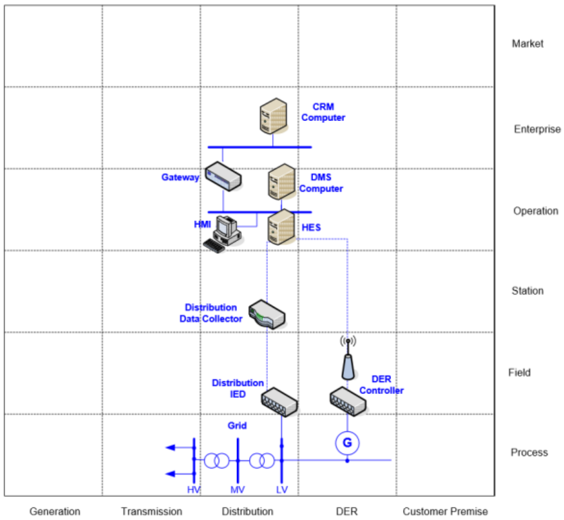


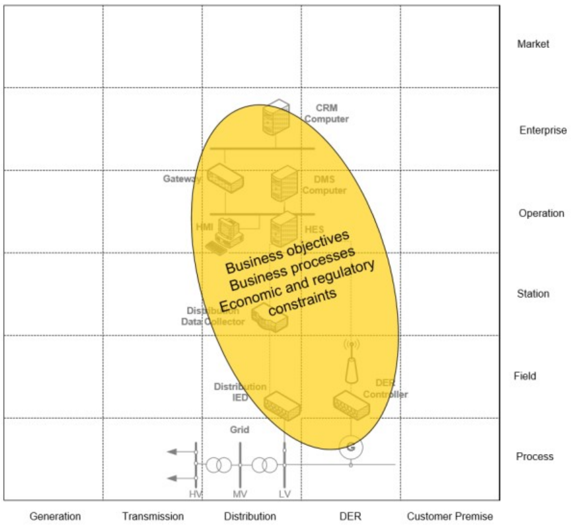
Figure 15. Use case diagram for "Control reactive power of DER unit" [27]**.**



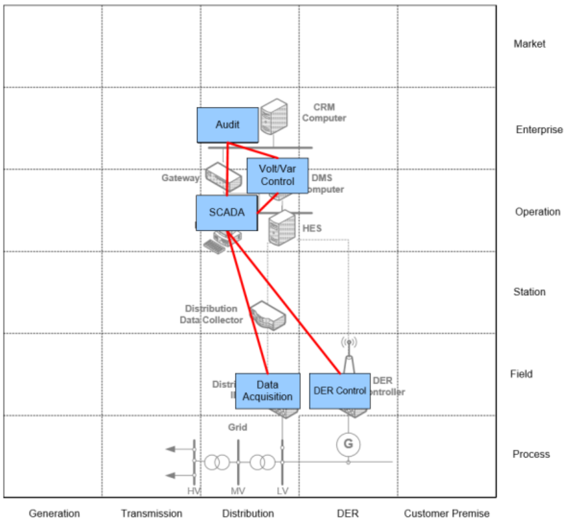
a) Actors and sub use cases mapped to SGAM



b) The Component Layer



c) The Business Layer



d) The Function Layer

Figure 16. Development from actor and sub use cases to the Function layer mapping, adapted from **[27].**

3.1.6 Tools

SGAM Toolbox is a free plug-in for Enterprise Architect software [30]. The SGAM Toolbox provides support for Smart Grid Architecture development in reference to the SGAM. Toolbox intents to support all stakeholders in Smart Grid system engineering process and provides a metamodel of the SGAM and along with it a Domain Specific Language (DSL) for modelling. Toolbox also provides numerous templates, reference data, documentation of development process, video tutorials and reference examples. Furthermore, especially SGAM layer presentation, UML, activity and sequence diagrams are easing engineering work.

3.2 Related architecture definitions

This chapter briefly presents selected architecture definitions from previous projects, which have influenced and focused the architecture definition work in the HEILA project. Architecture descriptions proceed from general architecture description, which covers ideas of the ICT architecture for energy domain, to ones that provide details about actors, their systems, functions and interfaces in related field of business.

3.2.1 Smart Energy Aware Systems project

Smart Energy Aware Systems (SEAS) project intends to provide ICT tools and systems for actors related to energy consumption, production and storage [31]. Project deliverable D1.3 presents ICT architecture called SEAS Reference Architecture Model (S-RAM). The S-RAM with its four distributed services enable energy actors to interconnect and to define and provide new energy services. Furthermore, the S-RAM takes into consideration state of the art and best practices to achieve compatibility with existing systems.

Description of the S-RAM uses SEAS communication terminology in order to generalize interactions [31]. Figure 17 illustrates the S-RAM and Table 5 presents the SEAS terminology used in the figure. The S-RAM divides into SEAS Core Domain (SCD) and SEAS Field Domain (SFD). Entities in the SCD rely on Internet Protocol (IP) and multiple transport protocols, for example, HyperText Transfer Protocol (HTTP). In comparison, entities in the SFD belong in one of the four capacity levels. The capacity levels vary from no support to full support.

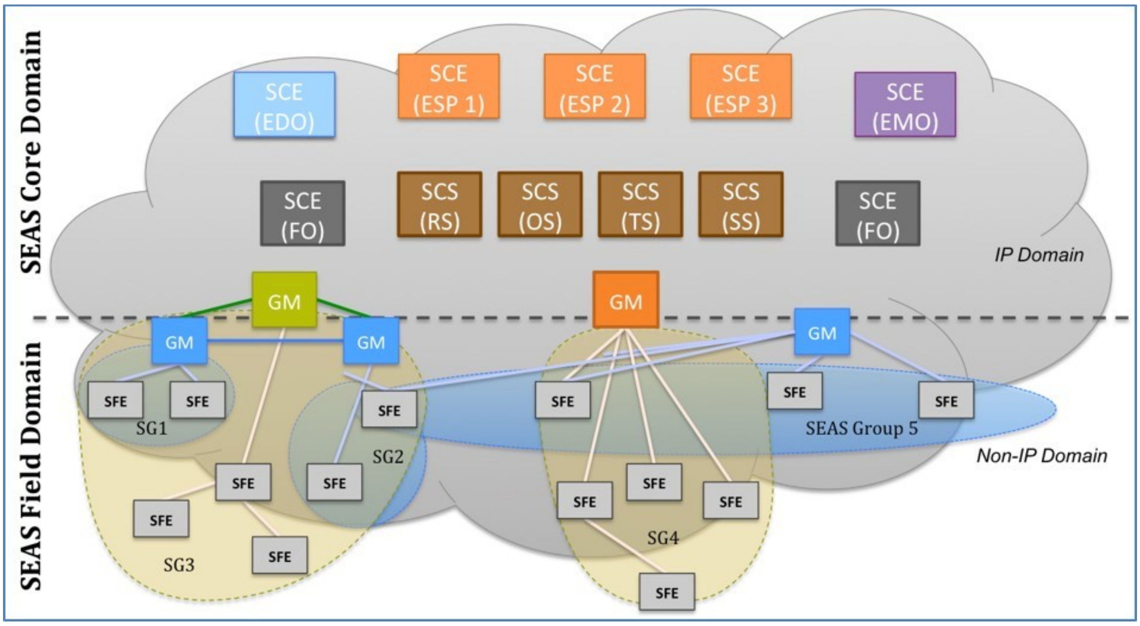


Figure 17. The SEAS Reference Architecture Model [31].

The SCSs function as services that enable finding and identifying parties [31]. Furthermore, after finding and identifying parties, the SCEs connect with a peer-to-peer principle. As shown in the figure, GMs can group both SFEs and other GMs as well. In addition, the GMs collect, store and possibly process energy information from SFEs.

Table 5. SEAS communication terminology, adapted from [31]**.**

Type	Name	Role	Matching example
SEAS Field Entity (SFE)	End User (EU)	Interact with other entities to plan and control energy management	Resident, Electric Vehicle (EV) Driver
	End Node (EN)	Entity consuming storing or producing energy or the node monitoring such entity	EV, Production Unit
	Non-SEAS EN (NSEN)	An End Node that does not support SEAS communication mechanisms	Home Appliance
Other	SEAS Group (SG)	A group of SFEs	Building, microgrid
SEAS Core Entity (SCE)	Group Manager (GM)	Entity managing one or several SGs. Capabilities to store and analyze collected data.	Energy Management System
	Energy Distribution Operator (EDO)	Entity distributing energy to an SG	Distribution System Operator
	Energy Market Operator (EMO)	Entity managing energy market	
	Energy Service Provider (ESP)	Entity providing an energy service to other SCEs	
	Energy Supplier (ES)	Entity that sells energy to EU. It may also buy resource if necessary	Energy Retailer
	Energy Producer (EP)	Entity that produces energy	Energy Producer
	Flexibility Operator (FO)	Entity in charge of managing local energy resource production	
SEAS Core Service (SCS)	Registration Service (RS)	Service to make other SEAS entities and services visible for others	
	Ontology Service (OS)	Service that links data to standardized vocabulary	
	Transaction Service (TS)	Service that is trusted third party, which is needed for monetary transactions and auditing	
	Security Service (SS)	Service that is trusted third party, which authenticates SEAS entities with each other	

The S-RAM splits into SCD and SFD, which is separation between constrained and non-constrained devices [31]. This is an advantage as the constrained devices may monitor or control environment and gateway principle regroups and links them properly to Internet.

Second advantage is that SCD allows use of different communication protocols so that the most suitable protocol for a given function may be used. In addition, distribution of the SCEs to several servers is possible, which is advantageous when cutting risk of single point of failure or maximizing availability.

3.2.2 IDE4L project

IDE4L project intends to define, design and demonstrate an active distribution network that includes RES and new loads and in addition, secures reliability of classical distribution networks [32]. Distribution automation and planning of active network belong to enhanced solutions of the project and Active Network Management (ANM), distributed automation of complete distribution grid for monitor and control, new roles of DSO and Aggregators, interactions of DSO/Transmission System Operator (TSO) and DSO/market actors and decentralized Fault Location Isolation and Service Restoration (FLISR). To implement IDE4L concepts, automation of primary and secondary substation, feeder, DER and LV systems need technical developments [33].

The IDE4L project builds on findings in projects ADDRESS [10] and INTEGRIS [34] and synthesizes their architectures for a starting point [33]. Figure 18 illustrates high-level description of the IDE4L architecture [33]. The figure presents main actor classes of the electricity supply chain and leaves out all the details. Moreover, *MO* is a Market Operator, *CA* is a Commercial Aggregator, *MGCC* is a MicroGrid Central Controller, *SAU* is a Substation Automation Unit, *ACT* is an actuator and *SENS* is a sensor in the figure.

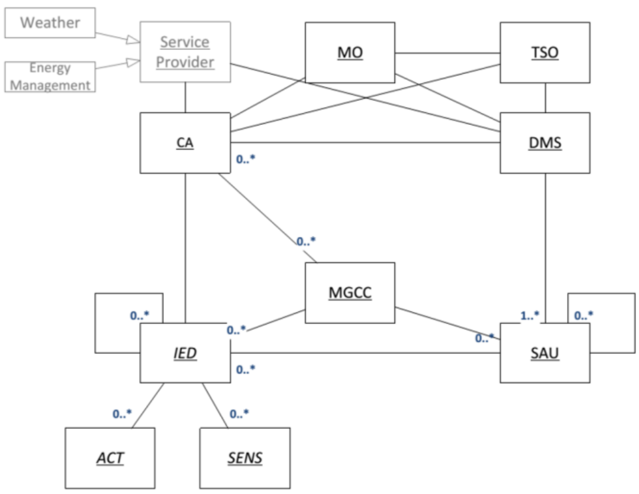


Figure 18. UML diagram for the IDE4L automation architecture [33]**.**

As shown in the figure, DMS may connect to multiple SAUs, which again may connect to multiple IEDs located, for example, in substations or DERs [33]. The goal in the IDE4L project is to decentralize traditional DMS functions to SAUs and IEDs, still maintaining the ruling role of DMS. The CA, MGCC and IED represent commercial classes and they have a similar hierarchical system as well. The CA does overall monitoring and management of aggregated DERs, whereas MGCC organizes DERs in particular network area. Moreover, the IEDs cover monitoring, protection and control of DERs and the DMS and CA connect to Service Providers. In addition, the IDE4L project uses the IEC 61850 and CIM to model information objects flowing between actors and uses Web Service (client-server), DLMS/COSEM, IEC 60870-5-104, IEC 61850 and Modbus interfaces [35]. Appendix 4 illustrates interfaces, databases and functions of DMS, CA and MGCC in more detail.

Related use cases

LV Real-Time Monitoring use case includes data collection of measurements, states and alarms from the LV grid into unique repository [33]. The use case includes mean values of voltage, current, reactive power, active power, transformers status, load profiles from LV customers and generations, PQ indexes, status of breakers/disconnectors, setpoints and alarms from secondary substation and related equipment. Moreover, different IEDs, EMS, Electronic Meter (EM), Meter Data Concentrator (MDC) system, Remote Terminal Unit (RTU) Power Quality Meter (PQM), Phasor Measurement Unit (PMU) belong to the related equipment. Figure 19 illustrates sequence diagram for the use case in case of an IED.

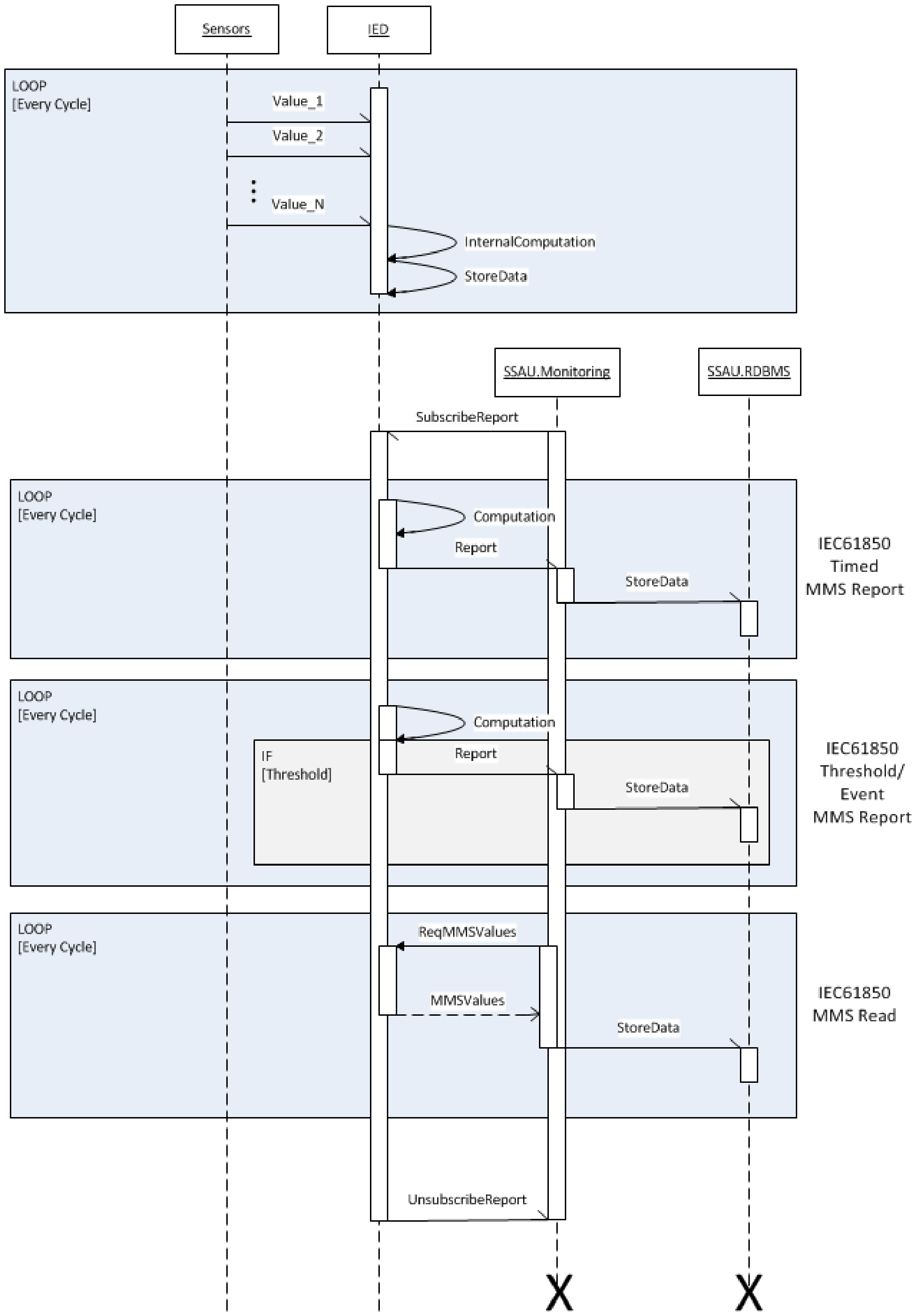


Figure 19. LV Real-Time Monitoring sequence diagram in case of an IED [36].

As shown in the figure, Secondary Substation Automation Unit (SSAU) subscribes to IEDs reports and stores data into its Relational DataBase Management System (RDBMS). Moreover, the figure presents different loops for timed, event and request based reports.

Conditional Re-Profiling (CRP) use cases cover Day-Ahead and Intraday market procurement and product (CRP) activation [33]. Flexibility providers and buyers submit flexibility bids to market during market clearing phase. Bids are for certain load area. After the market has cleared itself, it will send out information about accepted bids and market clearing price. This part involves CA, Market Operator and Balance Responsible Party (BRP). In CRP activation, buyer of flexibility (BRP, technical aggregator, TSO) identifies a need to active previously purchased product and sends an activation signal to the CA. The CRP product needs to be validated beforehand and real-time. This part may involve CA, BRP, TSO and DSO.

3.2.3 DREAM project

Distributed Renewable resources Exploitation in electric grids trough Advanced heterarchial Management (DREAM) project goals include envisioning of future distribution grid architectures when market driven prosumers are involved, allowing larger amounts of DERs by taking advantage of new coordinated response methods and concept and solutions for effective management of demand/response [37]. Furthermore, under normal circumstances DREAM -framework is located on the upper right corner of communications vs decision level matrix that Figure 20 illustrates, to make full use of demand response potential [38].

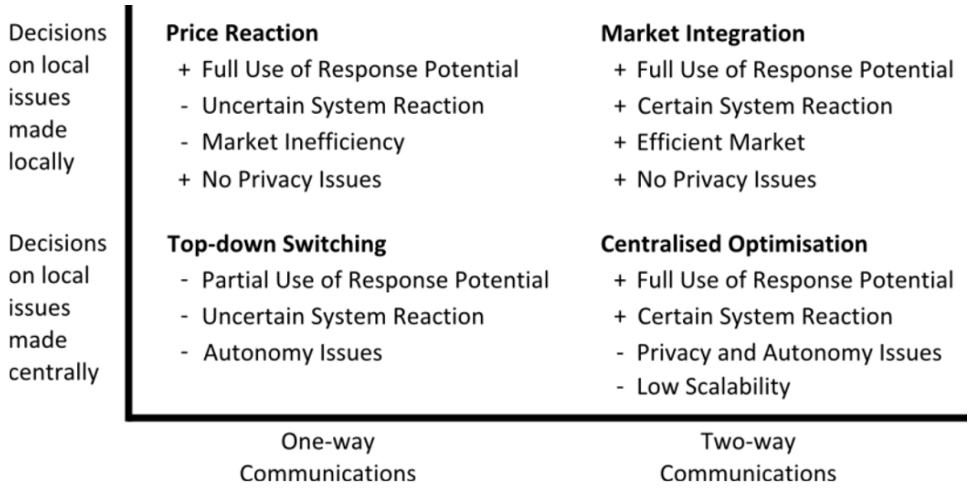


Figure 20. End user interaction. Communications vs decision level matrix [38].

DREAM project intends to build a local short-term balancing market that enables power balancing, voltage control and congestion management [39]. Figure 21 illustrates new market design of the energy supply chain.

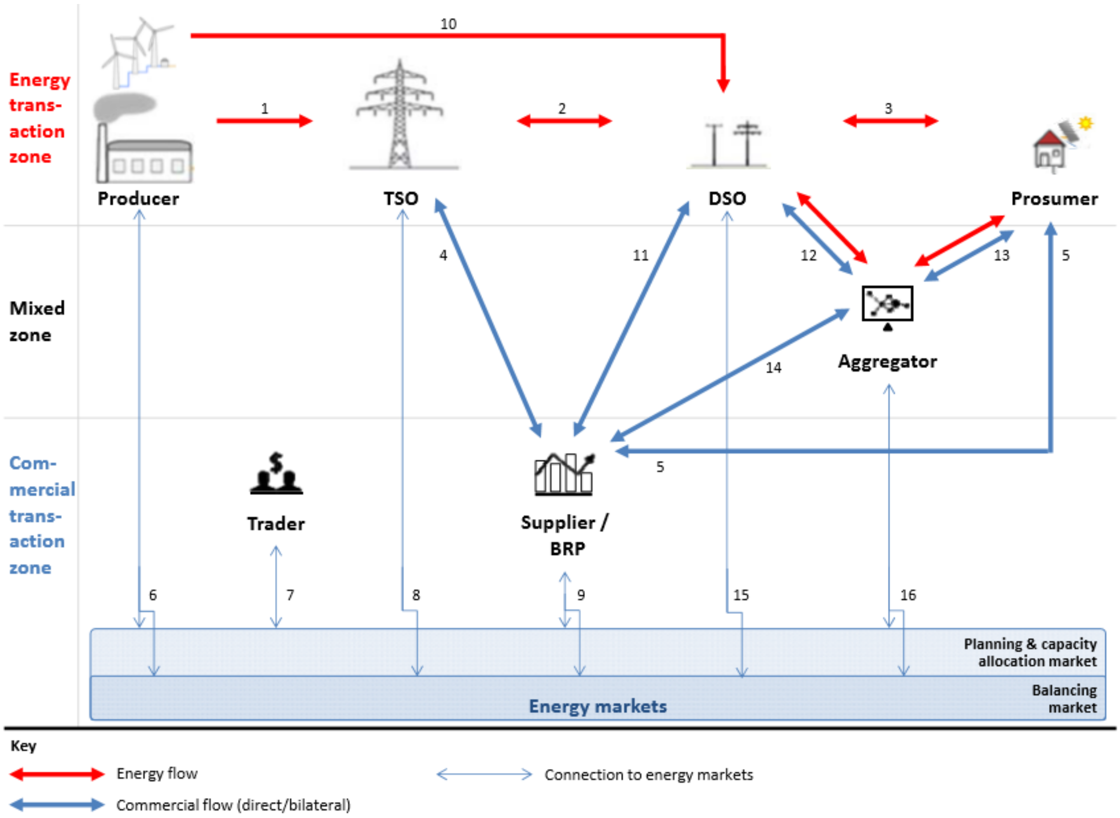


Figure 21. DREAM market design of the energy supply chain [40]**.**

Figure 22 presents possible way to include the DREAM project in the ICT infrastructure of distribution grid [41]. The infrastructure enables DREAM algorithms to monitor and control primary substations and MV Prosumers by RTU or Substation Automation, for example. To achieve distributed autonomous control of power distribution networks, the power distribution networks needs to be complemented by reliable and flexible communication capability, for example Internet of Things (IoT), FIWARE IoT and interface to network and devices (I2ND). Furthermore, the DREAM project uses Extensible Messaging and Presence Protocol (XMPP), HTTP and IEC 60870-5-104 protocols in tests [42], for example.

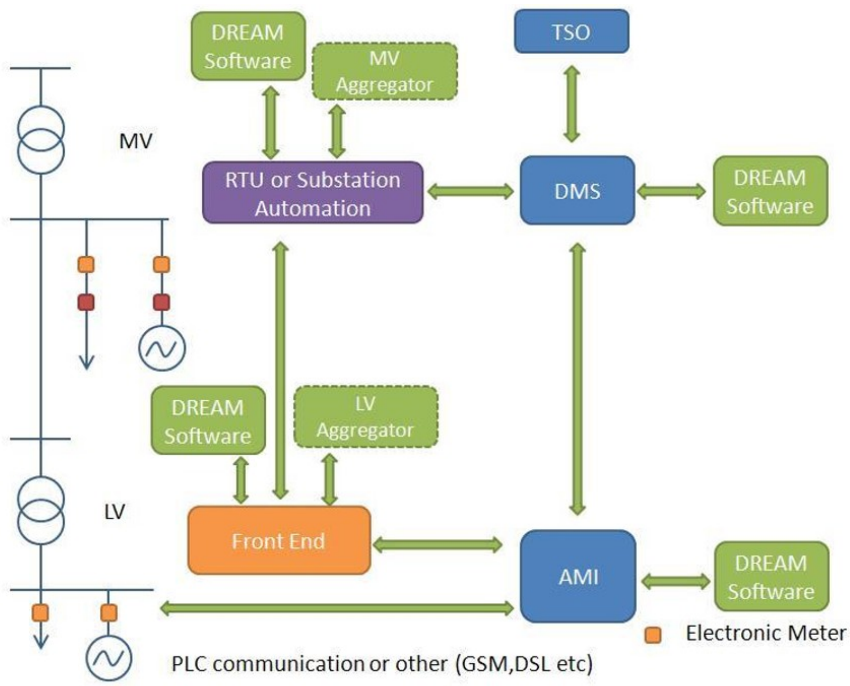


Figure 22. DREAM project integration of the ICT infrastructure [41]**.**

As shown in the figure, an Automated Meter Reading (AMR) or Advanced Metering Infrastructure (AMI) monitors the Prosumers on the LV level [41]. Front End (or Concentrator) and/or the RTU/Substation Automation could host the Aggregator. Furthermore, the DREAM Framework specifies that standards it is facing mainly are the IEC 61850 and CIM. The IEC 61850 standard covers all SGAM domains in Field and Station zones except Customer Premises domain and the CIM covers same domains as the IEC 61850 but Operation, Enterprise and Market zones instead of the Field and Process. In addition, different standards, for example KNX and Profibus, spread out in the Customer Premises domain from Process to Market zones.

Related use cases

LV cell provision of flexibility use case suggests methods to optimize use of flexibility for use of DSO voltage constraint management [39]. Goal is to form a local LV flexibility market and to arrange delivery of flexibility services. Figure 23 presents a representation of LV cell and its actors. The use case describes mechanism for use of short-term time scale LV flexibility to work out congestions and voltage deviations [38].

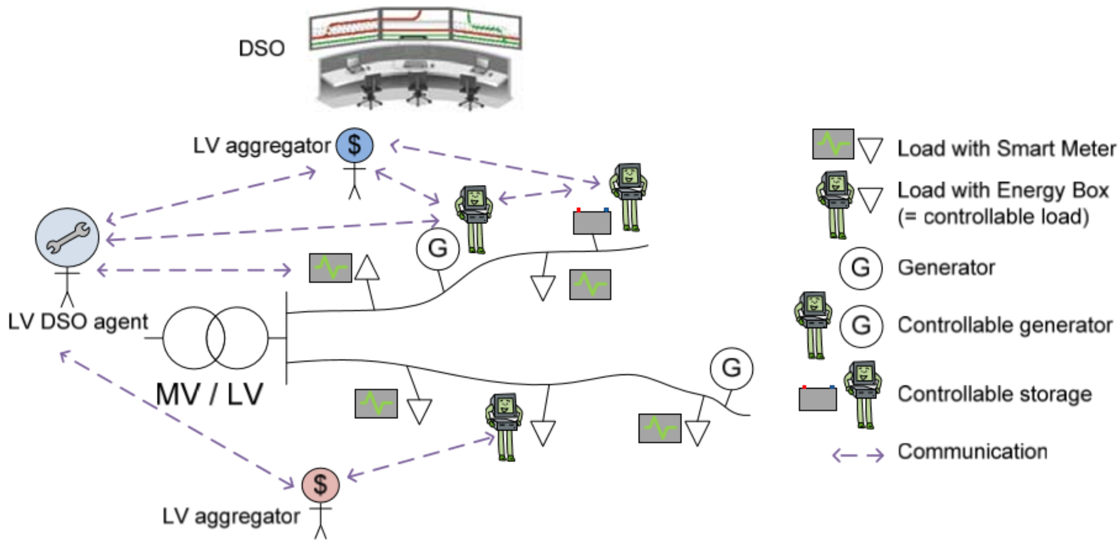


Figure 23. Representation of a LV cell and its actors [39]**.**

Preconditions for the use case presume that day-ahead and intraday processes are completed and new flexibility bids are feasible only for distributed control environment [38]. Figure 24 illustrates sequence diagram for the use case. In addition, the framework distinguishes between different grid operation modes. The operation modes are normal, critical and emergency, which result in “declared flexibility” (normal) and “undeclared flexibility” (critical and emergency) flexibility profiles.

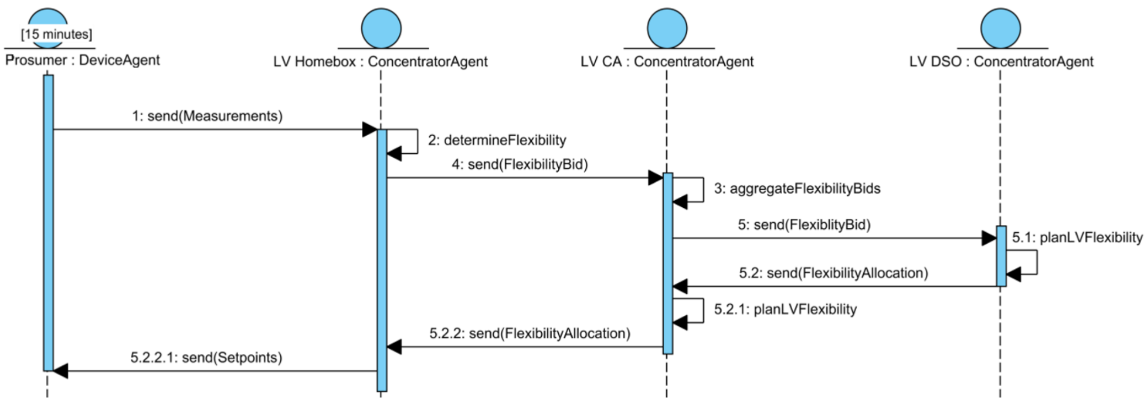


Figure 24. LV cell provision of flexibility sequence diagram [38]**.**

Provision of MV flexibility use case also suggests methods to optimize flexibility for use of DSO voltage constraint management [39]. Goal is to form a local MV flexibility market and to arrange delivery of flexibility services for both LV and MV levels. The aggregators operate at the substation level and provide flexibilities, which they aggregate from aggregators in the downstream levels. Figure 25 illustrates a representation of substation federations. The use case has a similar mechanism as the previous use case with extra aggregation level and MV prosumers [38].

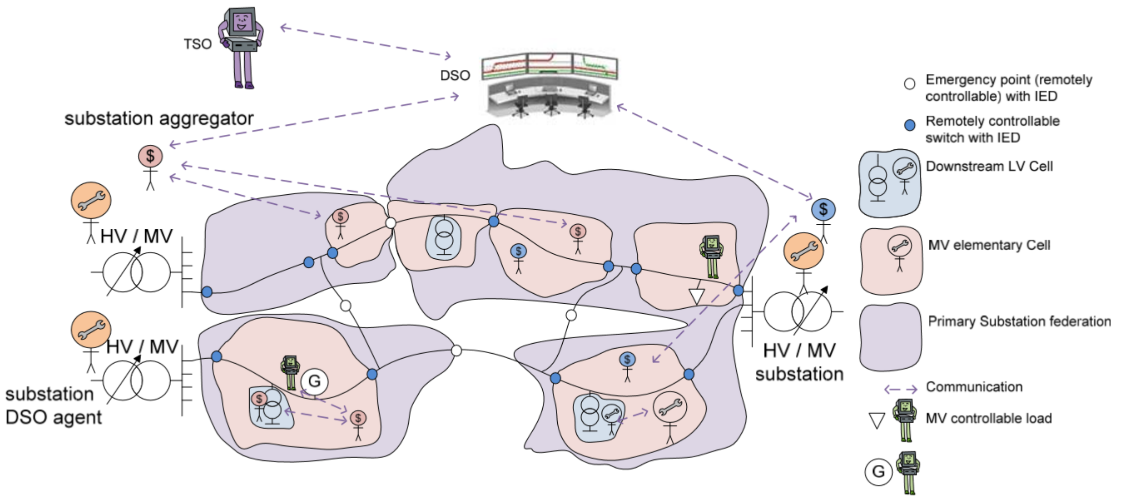


Figure 25. Representation of three dynamic substation federations [39].

Preconditions are also similar with the previous use case as flexibility bids are too late for existing markets [38]. Figure 26 presents sequence diagram for the use case. In this use case, also LV aggregator or LV cell operator is able to participate in flexibility provision on MV level.

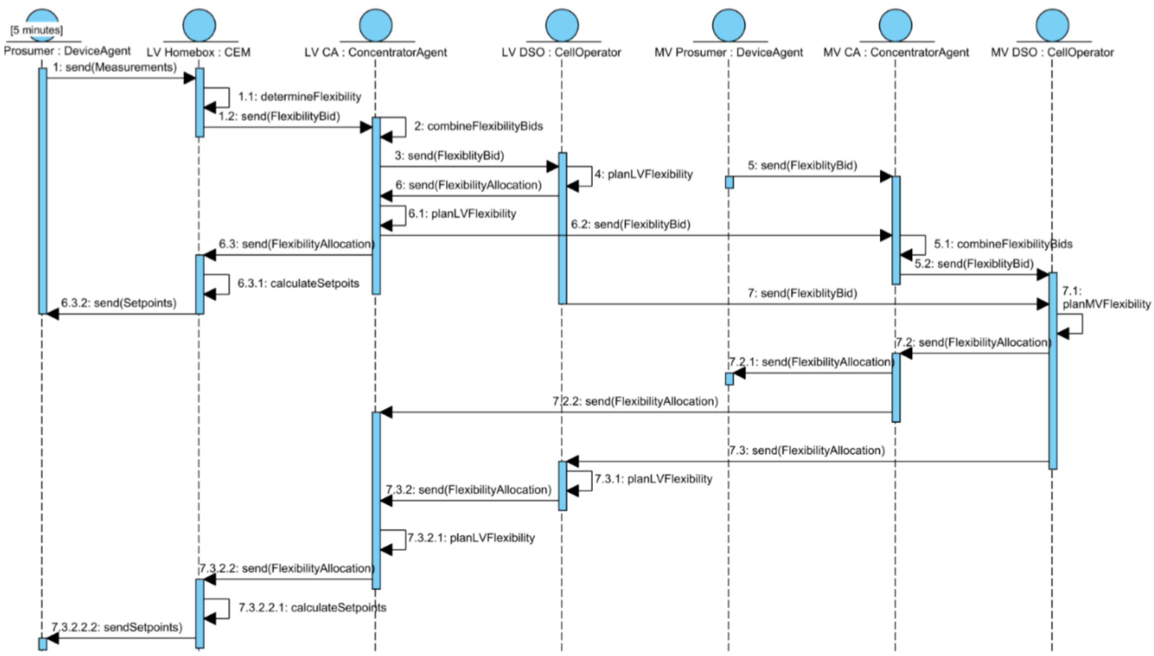


Figure 26. MV cell provision of flexibility sequence diagram [38].

Local LV control to solve a contingency in emergency situation use case provides mechanism to solve contingency [38]. In this use case emergencies develop when communication is disturbed or DSO notifies Prosumer about certain situation. Each case control both real and reactive power between flexible devices. Eventually, DSO releases the setpoint control. Figure 27 illustrates sequence diagram for the use case. Same mechanism applies to MV level.

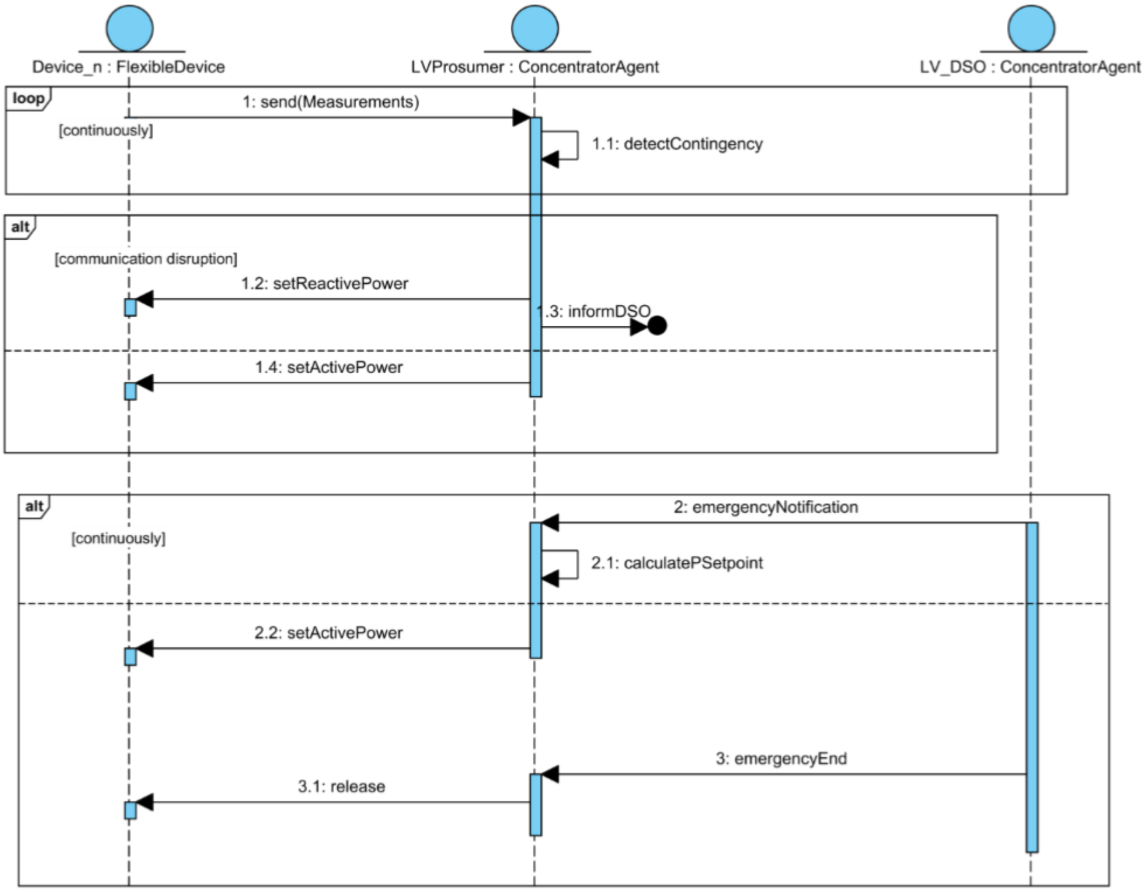


Figure 27. Local LV control to solve a contingency in an emergency situation [38]**.**

4. ENABLING INFORMATION MODELS, CONCEPTS AND PROTOCOLS

4.1 Information models

This chapter presents information models that are in use in the MultiPower laboratory or have potential for utilization in the SGTP to exchange information and for representation of devices. The information models are widely used in automation systems for power grid and electricity market management. Additionally, the CIM is considered as core standard [43] for the Smart Grid and it could deliver semantic data model for a Smart Grid platform [15].

Furthermore, this chapter provides description of physical device modelling with IEC 61850 standard's information model, mapping of the information model to IEC 60870-5-104 standard, presentation of specific parts of power systems based on CIM and harmonization of the IEC 61850 and CIM.

4.1.1 IEC 61850 and mapping to IEC 60870-5-104

IEC 61850 standard series addresses power utility automation systems and defines communication between intelligent electronic devices and related system requirements [44]. The standard series consists several parts and IEC 61850-7-X defines basic communication structure. Moreover, IEC 61850-7-2 defines information exchange, IEC 61850-7-3 and -4 information models and IEC 61850-80 presents guidelines for exchange of the information model, for example, with IEC 60870-5-104.

Structure of IEC 61850 information model bases on two levels [44]. First, real physical devices splits into logical devices (LD), second, the logical devices breakdown into logical nodes (LN), data objects and attributes. Figure 28 presents example of IEC 61850 data modeling. The standard does not specify arrangement of logical devices into physical devices, but splitting one logical device over many physical devices is off limits. Typically, logical device embodies a group of automation, protection or other functions. Logical device provide communication access point of physical device e.g. IED. Logical device also offers information about the physical device or about external device, it controls.

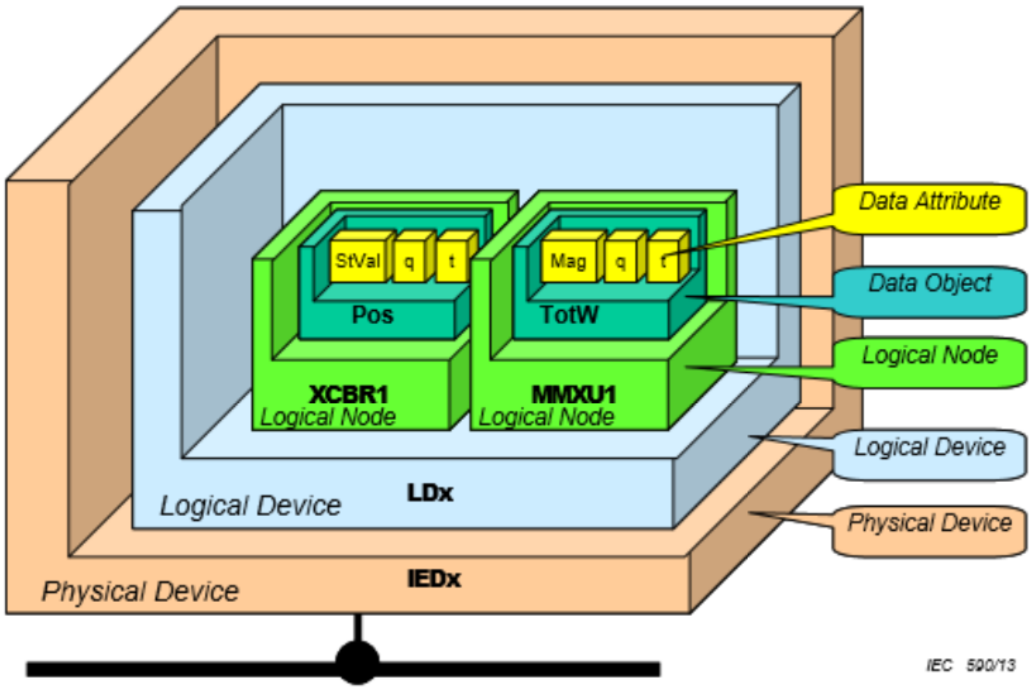


Figure 28. IEC 61850 data modeling [44]**.**

The standard divides the functions into the smallest entities, which information exchange uses [44]. These entities are logical nodes and several logical nodes construct a logical device. Logical nodes can be, for example, a measurement value *MMXU* or virtual representation of a circuit breaker *XCBR* and logical nodes may have different working mode than the logical device it belongs to. Logical nodes hold a list of data with dedicated data attributes and the data has a structure and precise semantic description.

The standard covers over 280 logical nodes for most common applications of substation and feeder equipment and most of the logical nodes provide information in five categories [44]. The categories are common logical node information, status information, settings, measured values and controls. Table 6 presents list of logical nodes groups.

The data objects hold set of data attributes which base on predefined types and structures named Common Data Classes (CDC), for a wide range of known applications [44]. Appendix 5 presents tables of some specific CDCs available with the COM600 in the MultiPower, circuit breaker logical node and definition for the *Controllable Double Point* (*DPC*). The Appendix shows, for example, that for the circuit breaker logical node, there is Data object called *Pos* representing position of switch and its CDC is *DPC* and it is mandatory.

Table 6. Logical nodes groups [45].

Group indicator	Logical node groups
A	Automatic control
C	Supervisory control
D	DER
F	Functional blocks
G	Generic function references
H	Hydro power
I	Interfacing and archiving
K	Mechanical and non-electrical primary equipment
L	System logical nodes
M	Metering and measurement
P	Protection functions
Q	Power quality events detection related
R	Protection related functions
S	Supervision and monitoring
T	Instrument transformer and sensors
W	Wind power
X	Switchgear
Y	Power transformers and related functions
Z	Further (power system) equipment

The standard references to these attributes as shown in Figure 29. The standard separates object names and object references [45]. Object names recognize instances at specific hierarchy levels, for example, *Q0XCBR1* is at logical node level. Furthermore, logical node names may have prefix and suffix, for example *Q0* and *1*, respectively. Object references are object names organized as a string. Additionally, functional constraint ST is not part of the reference to the attribute, as shown in the figure.

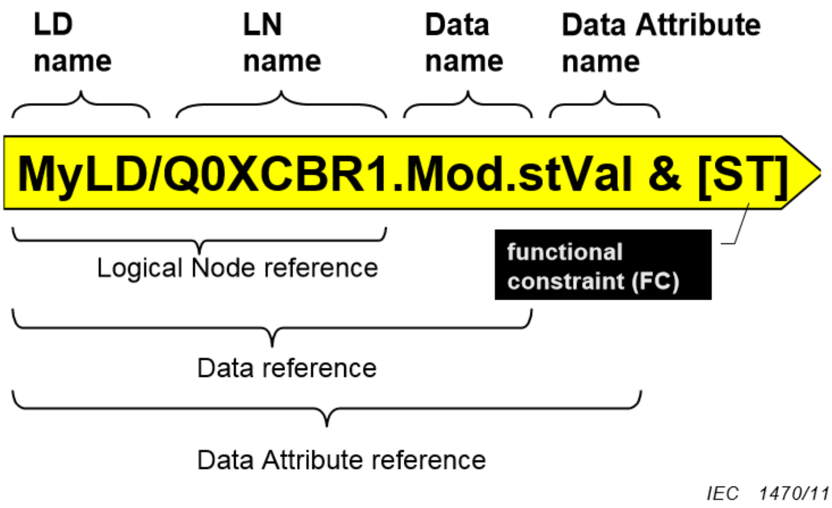


Figure 29. Object names and object references [45].

The standard defines SCL in part 6 [44]. The SCL allows exchange of device descriptions and system parameters between tools in a compatible way. Trough SCL configuration files it provides primary power system and communication connection description, IED capabilities and allocation of IED logical nodes to primary system in eXtensible Markup Language (XML) format. An SCL file defines an instance of the model, but its semantic is understandable by reference to model itself [46]. Figure 30 illustrates substation related part of the model in UML notation, but it is not comprehensive in the modelling sense.

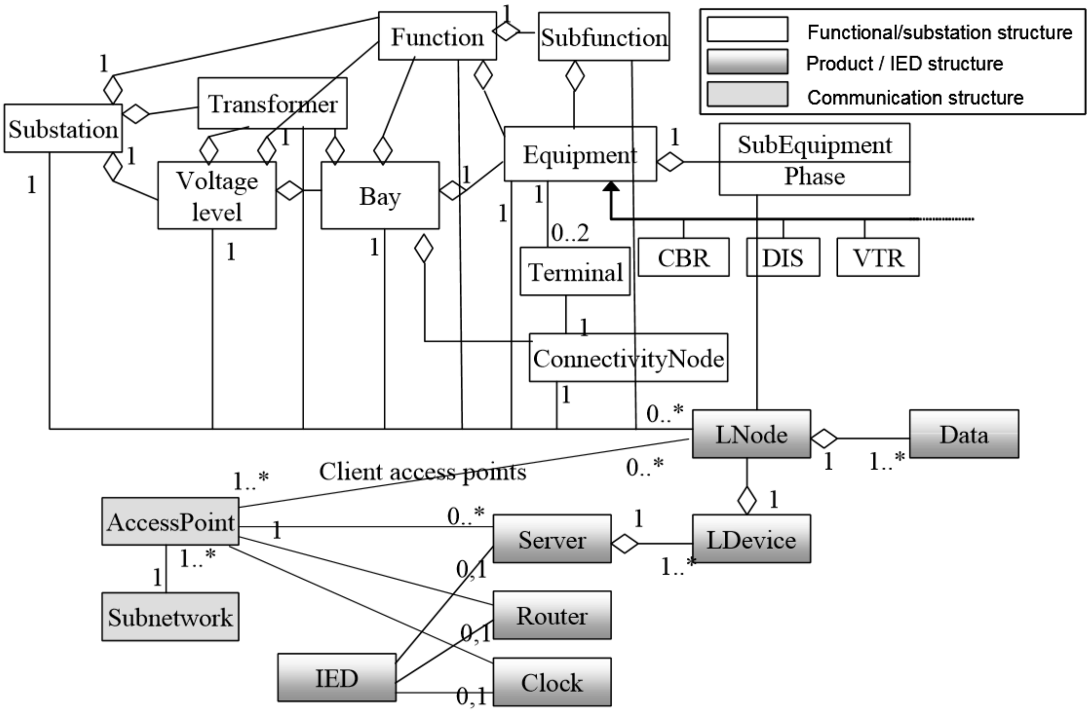


Figure 30. SCL object model [46]**.**

The figure shows three basic parts of the model [46]. Functional/substation structure presents process devices in the functional view according to IEC 81346-1, topology and order of the equipment and functions. Product/IED structure presents product related objects and logical nodes. Communication structure illustrates communication related object types and describes communication connections between IEDs.

Substation objects *Substation*, *VoltageLevel*, *Bay*, *Equipment*, *SubEquipment*, *ConnectivityNode*, *Terminal*, *Function* and *SubFunction* are analogies to the CIM model for energy management systems [46]. Transformer is special equipment, because it can be located below *Substation*, *VoltageLevel* or *Bay*. This hierarchical structure is for functional designations and chapter 4.1.2 provides more information of the CIM. Products consist of hardware and software to put on functions of the substation. Products cover only devices, which form the substation automation system and primary devices simply supply substation structure for functional naming purposes. The communicational structure, in comparison to the others, is not a hierarchical structure and it models connections at and across subnetworks. A subnetwork is non-physical connection node between access points, and by proper naming, correlation to the physical structure is possible. The access points provide a way for LDs or Clients of IEDs to connect to a subnetwork by physical port or by a logical address of the IED.

Mapping to IEC 60870-5-104

The 61850 standard presents guidelines on how to exchange information based on CDCs between substations and control centers by means of IEC 60870-5-101 and IEC 60870-5-104 [47]. Moreover, the standard defines mapping from a device-oriented information model to IEC 60870-5-101 and -104 functionalities such as Common Address of Application Service Data Unit (CASDU) and Information Object Address (IOA). When mapping the device-oriented information model to, for example, IEC 60870-5-104 the aim is to preserve the original structure. Figure 31 illustrates the mapping from IEC 61850 data model (LD “Feeder5”, LN “XCBR”) to IEC 60870-5-104 (Application Service Data Unit (ASDU) type 31).

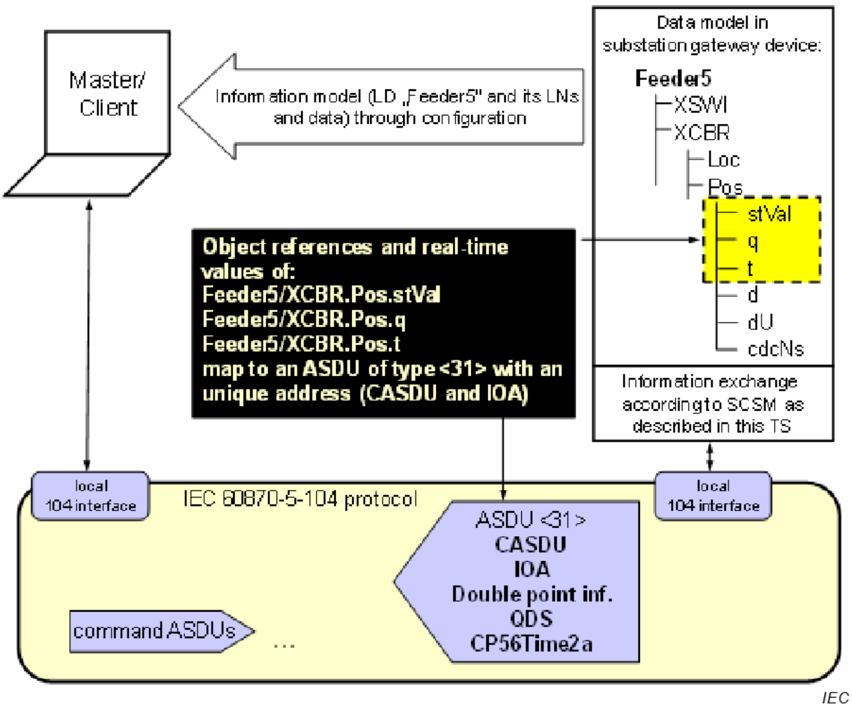


Figure 31. Mapping architecture [47]**.**

The standard maps LDs to the CASDUs [47]. The CASDU can be structured or unstructured, so if there is several stations and a single station covers multiple LDs, the standard recommends addressing scheme to identify stations and LDs. For one link there can be 65 534 CASDUs. Moreover, the standard maps LNs and data attribute references to the IOAs. LN class attributes are visible and defined implicitly. IOAs can also be structured or unstructured and the standard recommends a decimal approach for both cases. For one CASDU, there can be 65 536 IOA addresses.

The standard maps CDCs each data attribute to a specific IOA and each IOA relates to a specific ASDU type (with or without time) [47]. Appendix 5 presents mapping of aforementioned CDCs, excluding *CURVE*, *DPL*, *LPL* and *SAV* CDCs, because mapping of all CDCs to IEC-60870-5-104 is not possible, Common Data Classes *DPS* and above-mentioned *DP*C to IEC 60870-5-104 [47]. Furthermore, The Appendix presents mapping definitions for data attributes of *DPC* as they match with *DPS* attributes *stVal*, *q* and *t*, with functional constraint *ST* and definitions for data attributes of *DPC* for control services.

4.1.2 Common Information Model and Harmonization

Three different IEC standards cover the CIM, IEC 61970, IEC 61968 and IEC 62325 [43]. The IEC 61970 standard defines an Application Program Interface API for an EMS [43] [48]. Moreover, part 301 of the standard defines extensive base data model of the CIM. The IEC 61968 standard covers system interfaces for distribution management and 11th part of the standard expand the base data model on the IEC 61970 with objects for distribution management [43] [49]. The IEC 62325 standard defines communications between market participants and operators in European and US style markets [43]. Figure 32 illustrates different parts of the CIM. Furthermore, CIM profiles, for example Common Distribution Power System Model (CDPSM), ease use of the CIM since they contain only needed classes and associations as projects or companies often use only parts of the CIM.

The CIM has outgrown its original purpose and today there are different main use cases of the CIM [43]. First use case of the CIM is using it as domain ontology to provide vocabulary for conveying business messages between several systems. Moreover, it is possible to do custom integration with highly standardized semantics and syntax. Second use case of the CIM is utilizing it for topology data exchange, for example, with transmission or distribution grid. The CIM defines objects and relations to form a graph of the power grid and that bases on Resource Description Framework (RDF) serialization called CIM/XML. Third use case of the CIM is using it for more focused CIM models instead of the common data model and pre-defined serialization types. Pre-defined processes and payloads can act as blueprints when starting to use standards-compliant processes. The fourth use case of the CIM is employing it for communications and data exchange within EU- or US-style markets, extending the original EMS purpose.

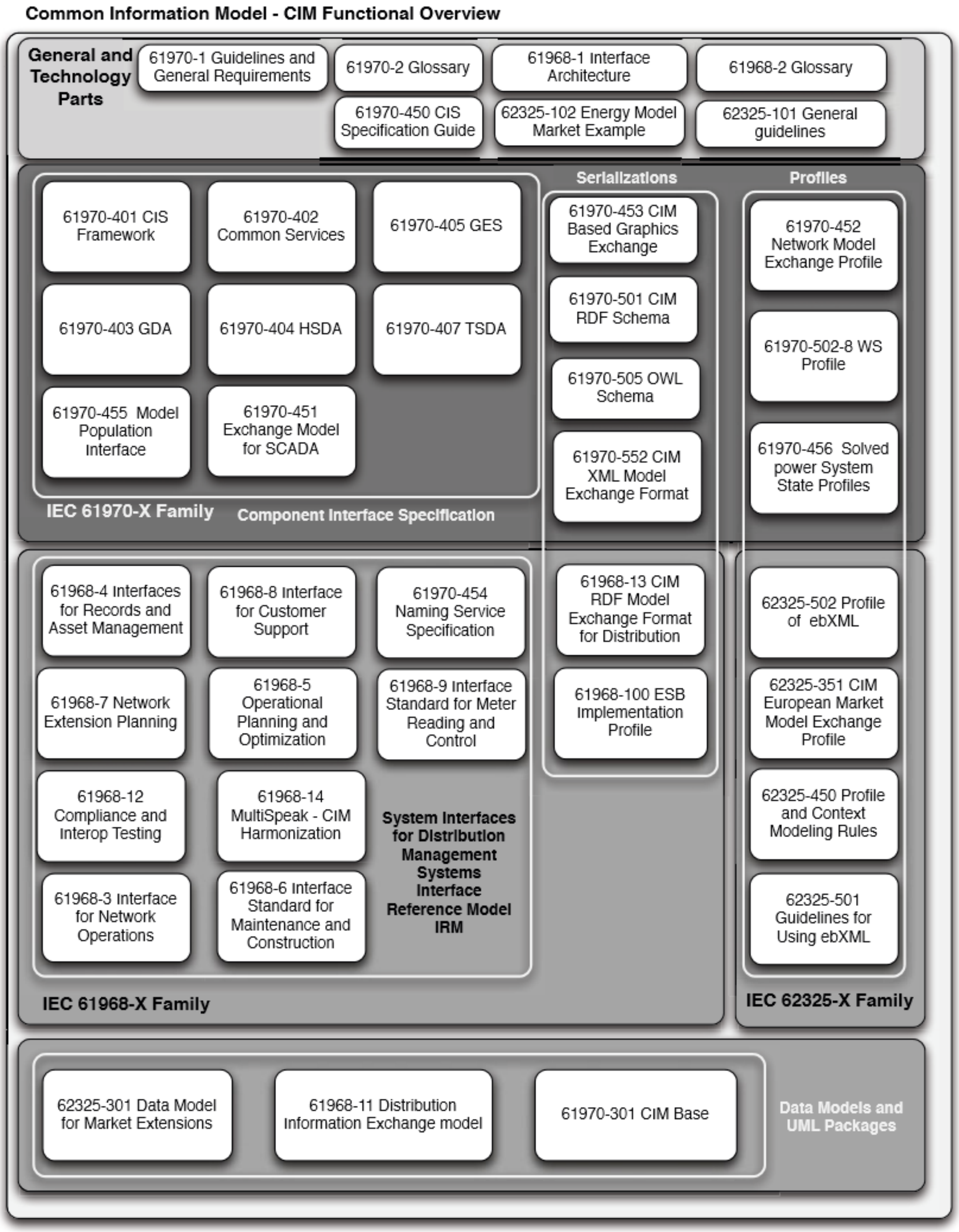


Figure 32. Overview of Common Information Model [43].

One of the use cases, the XML based message exchange uses interfaces that IEC 61968-3 to IEC 61968-9 standardizes or a custom interface [43]. The IEC 61968 recommends using standard message envelope that XML Schema defines and it should define a verb that identifies type of action, a noun that identifies type of payload and payload, which contains relevant data. Based on common structure, there is four stereotypes *RequestMessage*, *ResponseMessage*, *EventMessage* and *FaultMessage*. Figure 33 illustrates high-level message structure and structure of the *EventMessage* as an example. Figure 34 presents the structure in case of specific payload.

b) The EventMessage structure

a) High-level message structure

Figure 33. Message structure, adapted from [43].

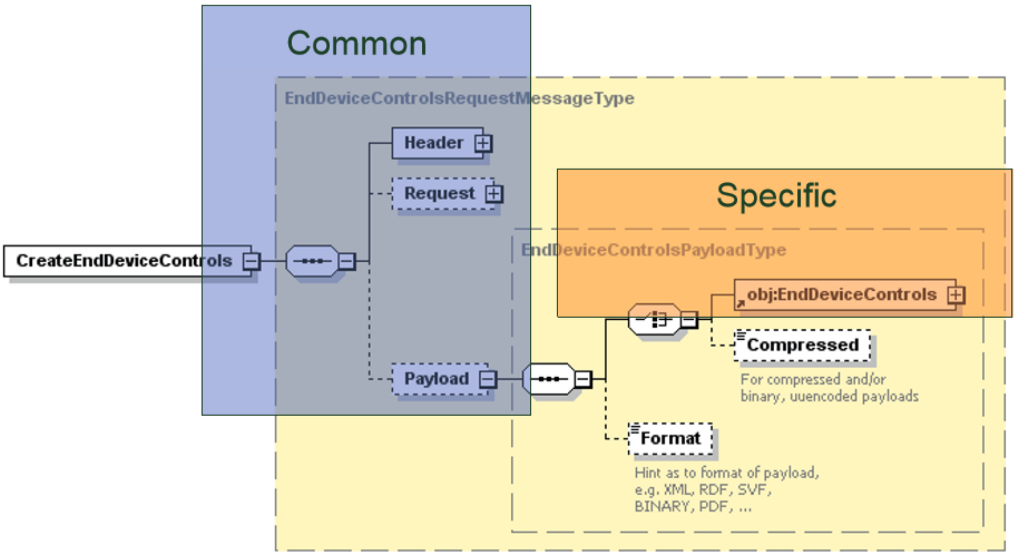


Figure 34. Specific payload structure [43].

Specific noun denotes each payload type and usually they result from the CIM data model [43]. Figure 35 presents an example artifact of *Switch* message payload. The *mRID*, *name* and *NormalOpen* also come from the CIM and they are a subset of attributes of the *Switch* object.

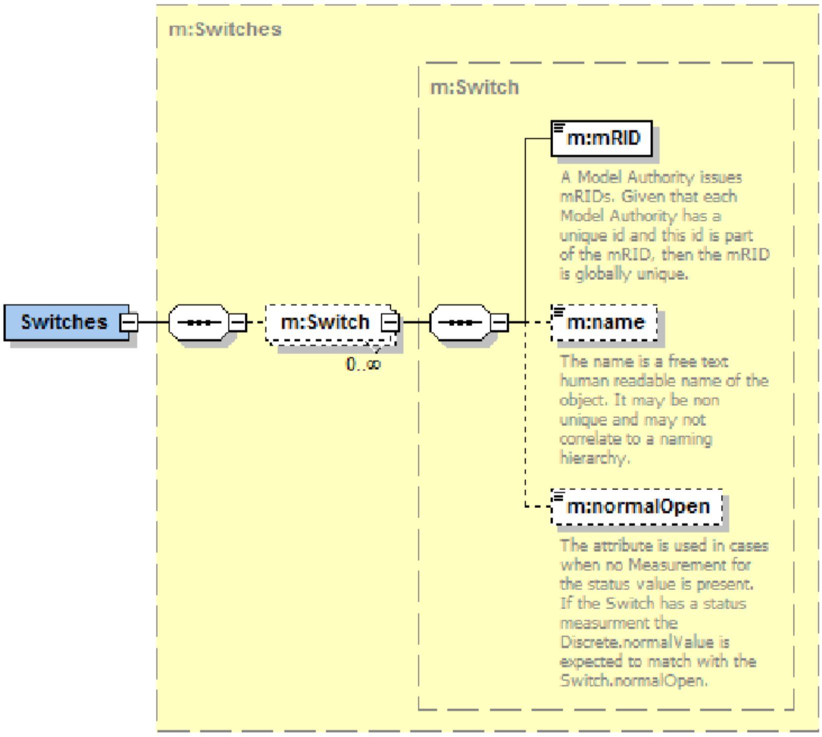
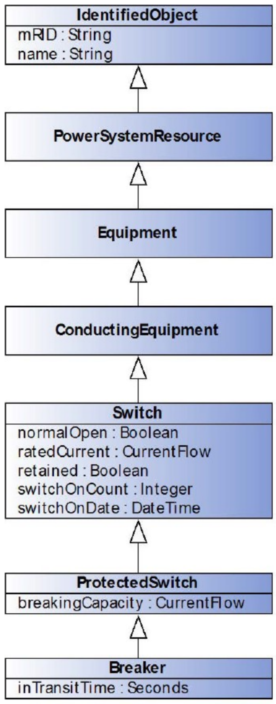
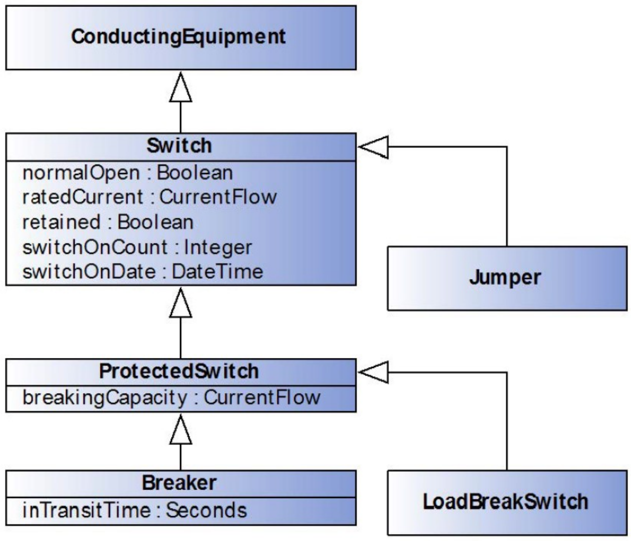


Figure 35. The Switch message payload [43]**.**

For another use case, the CIM uses class structure to define components, for example a *Breaker* [50]. Class inheritance for the *Breaker* is *IdentifiedObject*, a type of *PowerSystemResource*, a type of *Equipment*, a type of *ConductingEquipment*, a type of *Switch* and a type of *ProtectedSwitch*. Figure 36 illustrates the *Breaker* class and a *Switch* class with subclass hierarchy. Subclasses inherit attributes from parent classes, for example, the *Breaker* has an attribute *normalOpen* from the *Switch* class and an attribute *Name* from the *IdentifiedObject* class.



a) A Breaker class hierarchy



b) A Switch class with subclass hierarchy

***Figure 36. A Breaker class and Switch class with expanded subclass hierarchy in the CIM, adapted from* [50].**

The CIM uses Terminals and Connectivity Nodes to describe how different components connect to each other [50]. Figure 37 presents relationship between *Terminal*, *ConnectivityNode* and the *ConductingEquipment* classes. As shown in the figure, the *ConductingEquipment* class is not always associated to *Terminal* class. This is because only some of them carry current in network. In comparison, all *Terminals* associate to one specific *ConductingEquipment*. Furthermore, the *Terminal* class associate to a *ConnectivityNode*. Additionally, the *ConnectivityNode* is a zero impedance point.

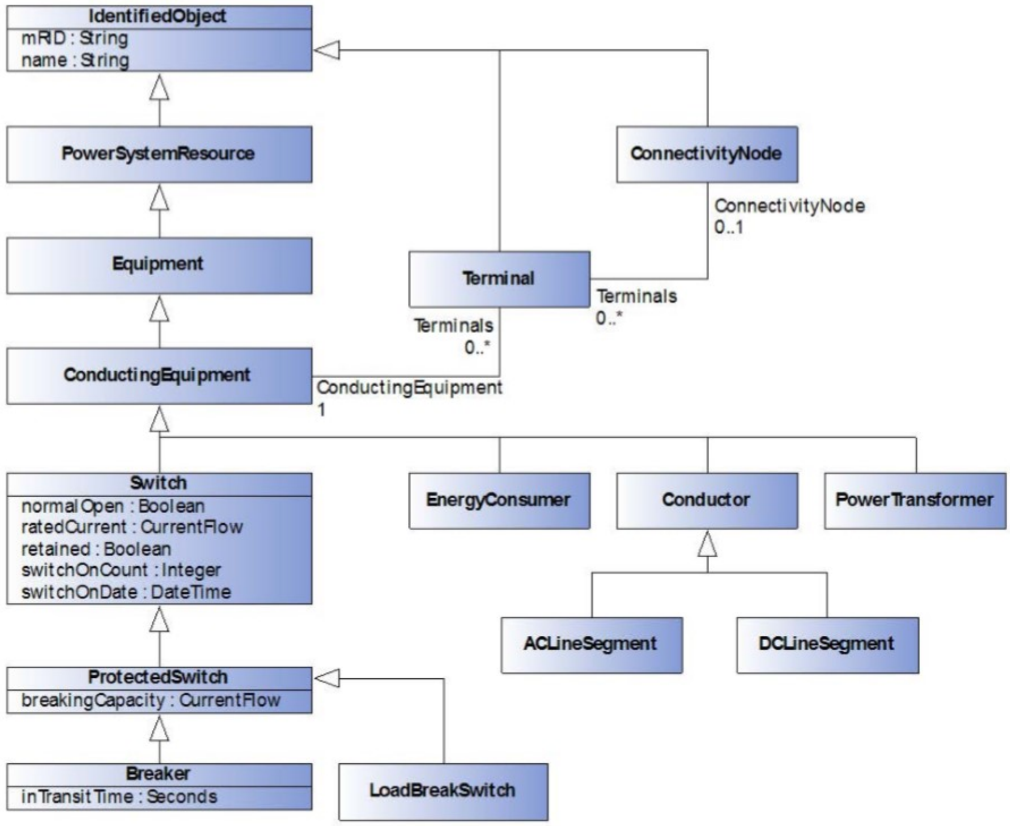


Figure 37. Conducting Equipment and Connectivity class diagram [50].

Figure 38 illustrates relationship between the conducting equipment, connectivity nodes and terminals with a simple example circuit [50]. As shown in the figure, the breaker has two terminals and therefore it is possible to distinct between two connection points, instead of a single component, as in real world power system network. Moreover, if the breaker is open then the measurement of voltage is different at the breakers terminals.

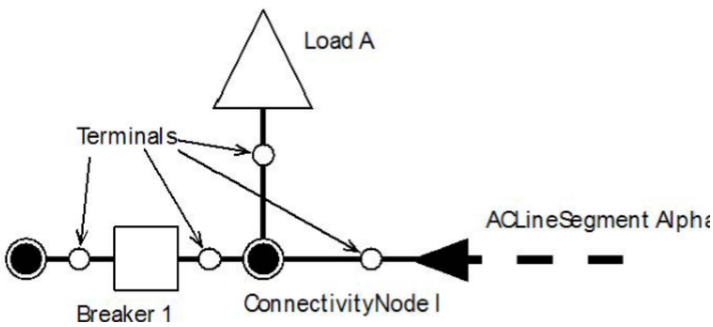


Figure 38. Simple example circuit [50].

Figure 39 and Figure 40 illustrates how more complex example circuit presented as Single Line Diagram transforms to the functional CIM representation [50]. The example circuit covers a substation and three different voltage levels of 17, 33 and 132 kV, which group pieces of equipment by means of *VoltageLevel* and *Substation* classes that are subclasses of *EquipmentContainer* class. The *EquipmentContainer* class allows grouping of equipment to denote electrical and non-electrical containment.

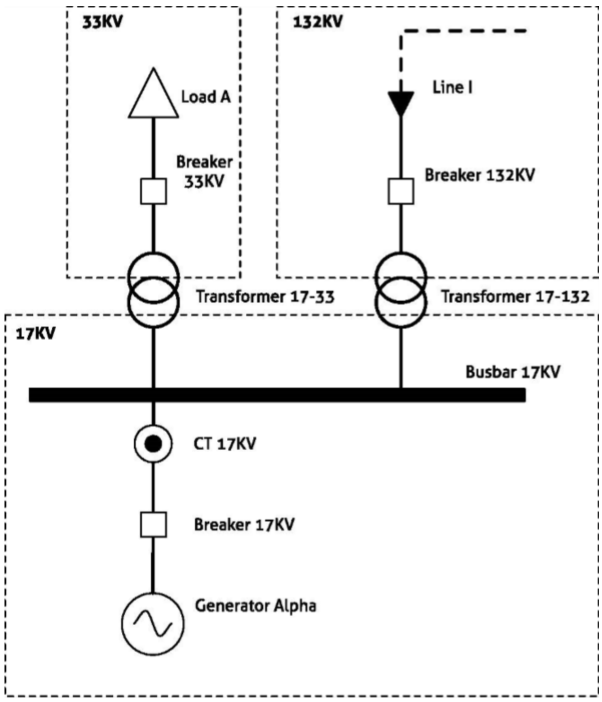


Figure 39. Example circuit as a Single Line Diagram [50]**.**

In addition to the functional view, the CIM covers asset view that provides information, for example to procurement, via an association between *PowerSystemResource* and *Asset* classes [50]. The asset view concerns, for example, how specific equipment is tracked, monitored and maintained. Therefore, changing a physical asset to another is possible without altering the functional equipment entry, which is a major advantage in certain situations.

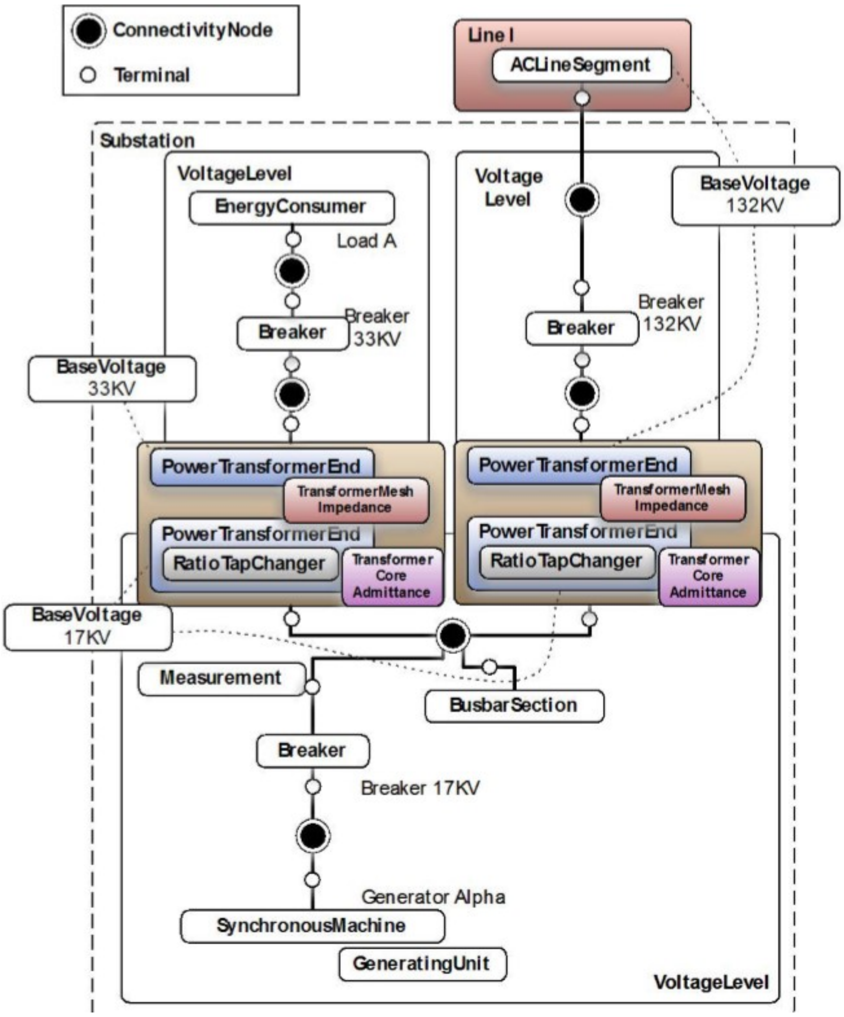


Figure 40. The CIM representation of the example circuit [50].

IEC 61850 and CIM harmonization

The CIM focuses to energy management systems and the IEC 61850 to substation automation systems while data from both standards deals with same context, therefore, harmonization is needed [43]. Diverse methods have been used since 2000 to address the problem.

Electric Power Research Institute (EPRI) concluded that it's possible to develop a unified model, which supports the CIM and the IEC 61850 standards for information exchange [51]. Furthermore, EPRI proposes changes to SCL to create unified model. However, general acceptance from other Standard Development Organizations (SDO) for proposed model is a challenge. In addition, there are several other approaches and one of them utilizes ontologies for finding alignments between two data models and presents a new ontology matching system for smart grid ontologies [52]. The ontology matching system contains schema-based and instance-based subsystems. Still, the offered system is not able to find all of the alignments automatically even it is able to leave behind other more generic systems in certain situations. Another approach intends to harmonize connectivity aspects of the CIM and IEC 61850 [53]. This approach uses certain object and model level harmonization principles to build up a harmonized model that base on equipment, container, connectivity node and coordinate views. In addition, transformation algorithms and Query/View/Transformation (QVT) of it support bi-directional transformation of the models.

4.2 Enabling concepts and protocols

This chapter gives brief overview of Smart API that is utilized in the HEILA research project for the SGTP. This chapter also introduces main characteristics of the protocols, which are main enablers of communication between actors in the use cases. Description of basic principles and features, security and Quality of Services (QoS) offer fundamentals about capabilities they provide.

4.2.1 Smart API

The Smart API bases on the SEAS project that paragraph 3.2.1 presents, and it's maintained and shared by Asema Electronics Ltd. [54].The Smart API offers an open source Software Development Kit (SDK) and four basic services, Find, Talk, Transact and Secure [55]. The Smart API connector technology has support for Java, C#, Python and C++ programming languages.

The SDK includes three predefined roles, a server, a client and a notifier [56]. The notifier is a party, which notifies its state to interested receivers. Furthermore, the Smart API utilizes elements such as, Jena, Paho-MQTT and web.py (HTTP), for handling RDF graphs and connections [57]. The Smart API uses linked data ontologies that eases integration work, generally. An ontology can be described as set of objects and relationships among them and it's also human readable [58]. In other words, it defines vocabulary for information exchange within described system or domain. Additionally, the data definitions are expandable [56]. The Smart API also contains code to support implementation of authentication and access control, for example OAuth2 [59].

In the SEAS project semantic data is the chosen technology for information layer because of its capability to define the exact meaning of data [60]. Furthermore, the information layer is set of ontologies. There are several techniques to define these ontologies or vocabularies, for example, RDF, RDF Schemas and Web Ontology Language (OWL) [61]. The RDF enables adding machine-readable information, processing with third party applications and extends related information [62]. The RDF utilizes graph-based data model, where core structure is a set of triples, which consist a subject, a predicate and an object, called an RDF graph [63]. The RDF graphs can be written, for example, with Turtle, JSON-LD, RDFa and RDF/XML formats [62]. Figure 41 illustrates structure and example of RDF graph with two nodes. Furthermore, there are three types of nodes, Internationalized Resource Identifiers (IRI), literals and blank nodes.

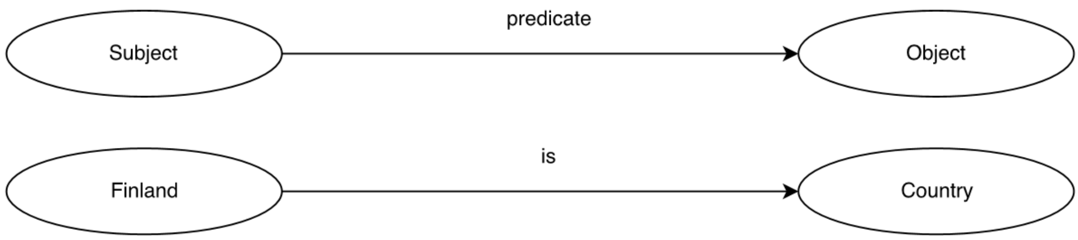


Figure 41. Structure and example of an RDF graph with two nodes, adapted from [63][60]**.**

The IRIs and literals denote resources, for example, physical things, abstract concepts and numbers [63]. The blank nodes state that something with the given relationships exist, but does not explicitly name it. The resources denoted by an IRI and a literal are known as referent and literal value, respectively. There are literals that have datatypes, which state variety of possible values, and special kind of literals that are language tagged. The predicate indicates relationship between resources and it is an IRI by itself that denotes a property.

Group of IRIs, a collection intended for use in RDF graphs, is an RDF vocabulary [63]. Generally, the IRIs within RDF vocabulary begin with a namespace IRI, furthermore, some namespace IRIs have shorter name, namespace prefix. For example, namespace prefixes rdf, rdfs and xsd stand for the built-in RDF and RDF Schema vocabularies and the RDF compatible XML Schema Definition (XSD) types. XSD basically describes structure and constrains of contents in XML document [64].

The RDF Schema offers tools to describe groups of related resources and their relationships [65]. Furthermore, the RDF Schema is an extension for RDF vocabulary. The RDF Schema uses property-centric approach so that, for example, property *Author* has domain *Document* and a range of *Person* instead of having a class *Book* with an attribute *Author* and a type *Person*. This is beneficial when extending definitions of existing resources since there is no need for re-definition of original classes.

The OWL is an ontology language and it can be used with information written in RDF [66]. Generally, RDF documents convey the OWL ontologies [67]. The OWL represents complex knowledge about things, groups of things and relations between them. Computer programs can reason the knowledge the OWL delivers. The OWL uses Axioms, Entities and Expressions to represent knowledge. The Axioms are statements that an OWL ontology indicates and they can be very subtle. The Entities refer to real world objects and the OWL denotes objects as *Individuals*, categories as *Classes* and relations as *Properties*. Furthermore, the *Properties* splits further to *Object properties*, *Datatype properties* and *Annotation properties*. The Expressions are complex descriptions that combination of basic entities form, for example, via *Constructors*. Figure 42 illustrates an example about the underlying structure of quantities and a unit from set of ontologies [68] in Turtle and Figure 43 presents important information that can actually represent the unit in order to simplify semantic structure [60]. Gray background color points out the quantities and a unit, rectangles are for the underlying structures and arrows show connections in the semantic structure.

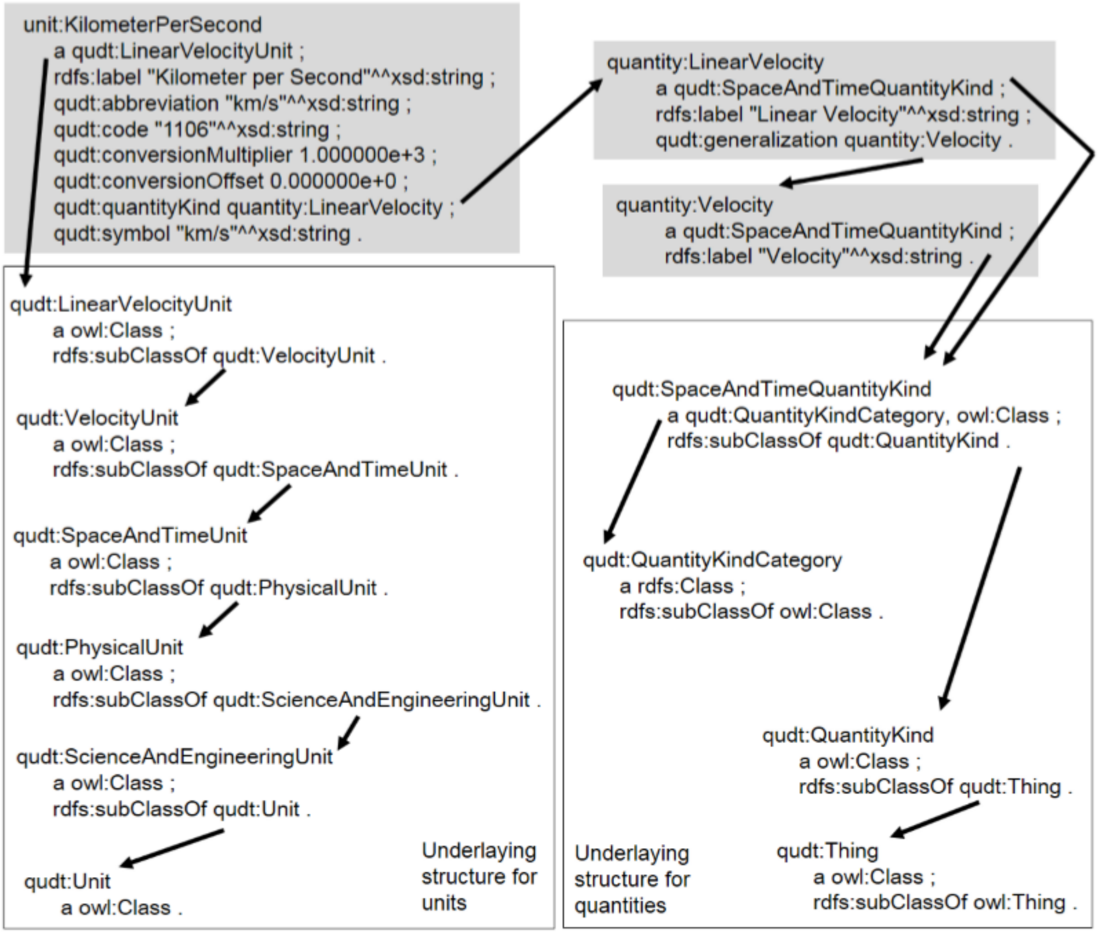


Figure 42. An example of structure for quantities and units of Quantities, Units, Dimensions, and Types (QUDT) ontologies [60]**.**

As shown in the Figure 42, a resource `unit:KilometerPerSecond` represents the unit kilometer per second and a type `qudt:LinearVelocityUnit` defines it [60]. The structure of `qudt:LinearVelocityUnit` again spreads several levels via `rdfs:subClassOf` to `qudt:Unit`. As the Figure 43 shows, information filtering results in much more simpler representation of the semantic structure.

```
unit:KilometerPerSecond
      rdf:type qudt:LinearVelocityUnit ;
      rdfs:label "Kilometer per Second"^^xsd:string ;
      qudt:abbreviation "km/s"^^xsd:string ;
      qudt:code "1106"^^xsd:string ;
      qudt:conversionMultiplier 1.000000e+3 ;
      qudt:conversionOffset 0.000000e+0 ;
      qudt:quantityKind quantity:LinearVelocity ;
      qudt:symbol "km/s"^^xsd:string .
```

Figure 43. A resource description. Bold underlined text points out important information [60]**.**

4.2.2 HyperText Transfer Protocol

HTTP is a flexible request/response protocol that is stateless and uses semantics and self-descriptive message payloads, for information systems [69]. Figure 44 and Figure 45 presents distinction between stateful and stateless designs. Moreover, the HTTP is a generic interface protocol and it can act as intermediary by design. In general, the HTTP defines syntax and intents of communication and expected behavior of recipients.

Figure 44 illustrates a stateful service, which stores a variable to keep record of where application left off in order to being able to respond for next requests [70]. This complicates services and it requires lots of up-front consideration.

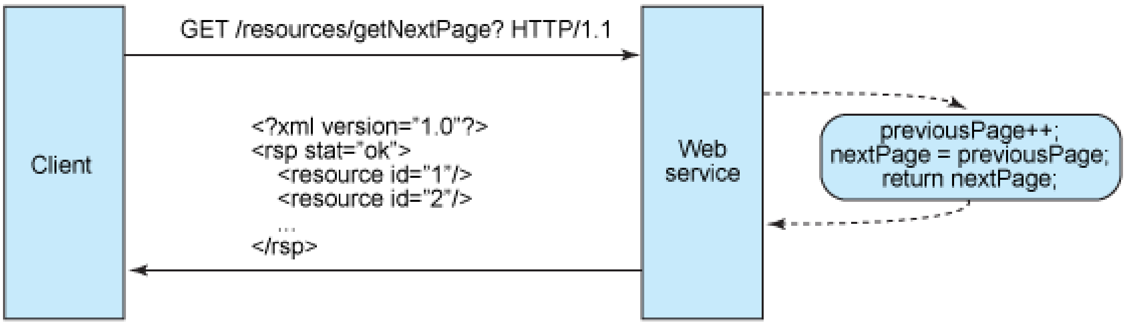


Figure 44. Stateful design [70]**.**

Figure 45 presents a stateless service, which leaves most of responsibility of storing the state for client application [70]. Server is responsible for creating response, which allow client to maintain application state on its own. For example, client has to request the actual page number instead of just asking for next page.

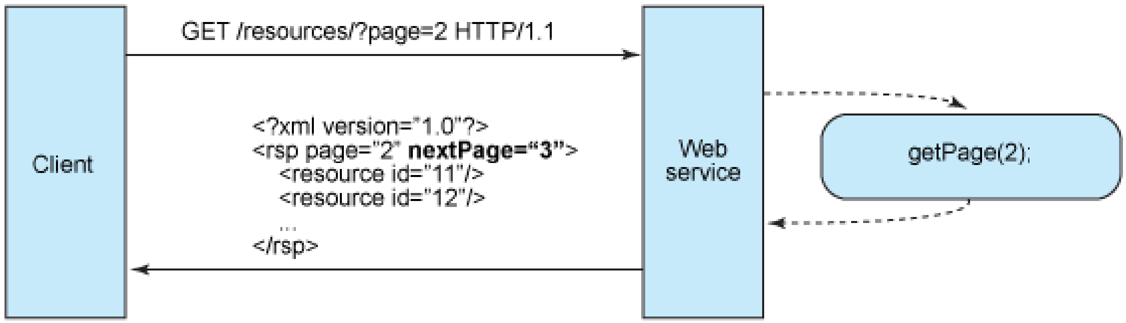


Figure 45. Stateless design [70]**.**

The HTTP uses Uniform Resource Identifier (URI) to point out target resource and relationships concerning resources [69]. Common first step of HTTP communication consist of a client sending `GET` request that includes a method, URI, protocol version, header fields and message body with possible payload. A server follows with one to many responds, with a status line, header fields and message body with possible payload. If the URI contains *http* it indicates to TCP based services and in addition, *https* indicates to Transport Layer Security (TLS) secured connections. The host identifier in the URI can be an IP address or registered name with a name resolution service, for example, Domain Name System (DNS).

The HTTP also take advantage of cache that reduces response time and network bandwidth consumption [69]. The cache is effective with request/response chains, when cached response cuts the chain.

4.2.3 MQ Telemetry Transport

MQ Telemetry Transport (MQTT) is an open, simple and light client server messaging protocol with publish/subscribe architecture [71], [72]. It is easy to implement and supports thousands of remote clients by a single broker (server). MQTT utilizes TCP/IP as a network protocol. MQTT minimizes requirements for network bandwidth and processing capabilities, so it is ideal for use in communication in Machine-to-Machine (M2M) and IoT environment.

Client is a program or device, which can publish or subscribe to Application Messages. Application Message carries data in MQTT protocol [72]. Application messages are QoS and Topic Name associated. Broker is a program or device, which operates as an intermediary between Clients. Subscription includes a Topic Filter and a maximum QoS. Figure 46 presents connection principle of MQTT network protocol.

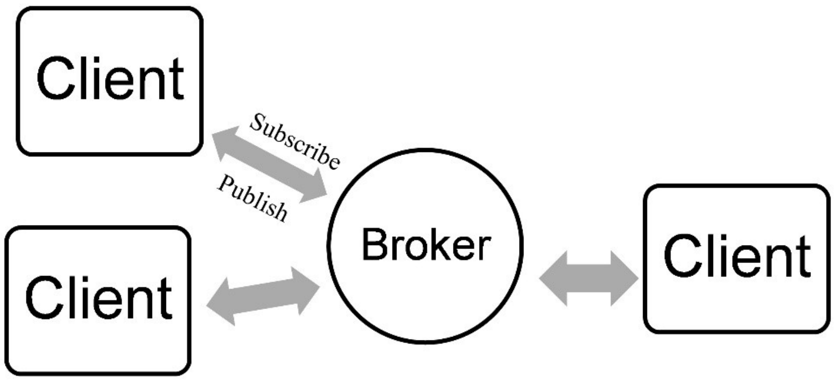


Figure 46. Connection principle of MQTT protocol, adapted from [73]**.**

Publish and subscribe are two of fourteen control packets in MQTT [72]. Control packets are packets of information that travel across the Network Connection. For example a `PUBLISH` packet carries an Application Message, which broker forwards to interested clients. Appendix 6 presents all control packet types.

MQTT benefits from its features like being agnostic about data types [71], [72]. This means that content of the messages are not required to be in any certain format. A small transport overhead, minimized protocol exchanges and notification mechanism about abnormal disconnection are beneficial as well. Furthermore, three qualities of service allow flexibility in management of different types of messages. QoS levels are *at most once*, *at least once* and *exactly once*. On higher QoS levels, effort is increasing by the server to ensure message delivery.

Lowest level of QoS is 0 *at most once*, which delivers messages according to the best effort of underlying network [71], [72]. In other words, client or server is not expecting a response of any kind. In case of failure to deliver the message, there is no retry attempt. Furthermore, the message can reach the broker once or never. QoS level 1 is *at least once*, which ensures the message delivery, but duplicates may occur. `PUBACK` receipt packet confirms the message delivery. If failure detection is in action, or the client does not receive `PUBACK` receipt packet, it will resend the packet with `DUP` flag set. The broker then republishes the message to the subscribers and resends `PUBACK` packet. As a result, the message arrives at the broker at least once. Highest level of QoS is 2 *exactly once*, which delivers messages without possibility for duplicates. The client or the server ensures that the message deliver take place only once. For example, when a client delivers a message to a server, the server will store the message and response with `PUBREC` packet. Once the client receives `PUBREC`, it will response with `PUBREL`, which will result to message delivering to the subscribers by the server and another response to the client with `PUBCOMP`, thus guaranteeing the message delivery. The Appendix 6 presents protocol diagrams for different levels of QoS to show possible implementation approaches.

MQTT protocol specification provides mainly guidance and recommendations concerning security [72]. Specification presents use of WebSocket for network transport security or adding specific security profile to the MQTT protocol to enhance security. Therefore, it is implementer's responsibility to provide suitable security features. The idea is to use common and recognized standards with MQTT instead of embedding non-standard security mechanisms [74]. For example, MQTT's client identifier and X.509 certificate and TLS provide options for authentication, authorization and transport encryption depending on use case [75], [76]. In addition, payload encryption and checking data integrity are some of the options among security mechanisms [76], [77].

5. ARCHITECTURE MODEL DESCRIPTION

This chapter presents the developed architecture model with the SGAM. As stated before, the architecture was developed in collaboration with the research project team and the architecture model that this chapter presents is work of the author. The chapter presents the layers in the same order as processed with the Enterprise Architect and SGAM Toolbox. The actual Enterprise Architect files are delivered to private research project website.

Generally, the architecture model presents domain (e.g. DMS) and function (e.g. weather forecast) specific systems and leaves out other systems focusing on administration features such as clock reference and authentication and authorization systems. Furthermore, the presented architecture model bases on DSO Flexibility and Microgrid Monitoring use cases. Therefore, in case of other use cases the architecture might have slight differences that different actors cause. Although, main characteristics should remain unchanged.

5.1 DSO Flexibility

The main target of the use case is to improve power quality in the network with the use of flexibility that the Prosumer possesses. The Aggregator, Flexibility Market Operator (FMO) and Service Provider supply services that support realization of the main functionality. Figure 47 displays the DSO Flexibility use case diagram. The DSO Flexibility use case is a HLUC and it invokes Primary Use Cases (PUC), for example the Microgrid Monitoring use case. Table 7 presents descriptions for logical actors.

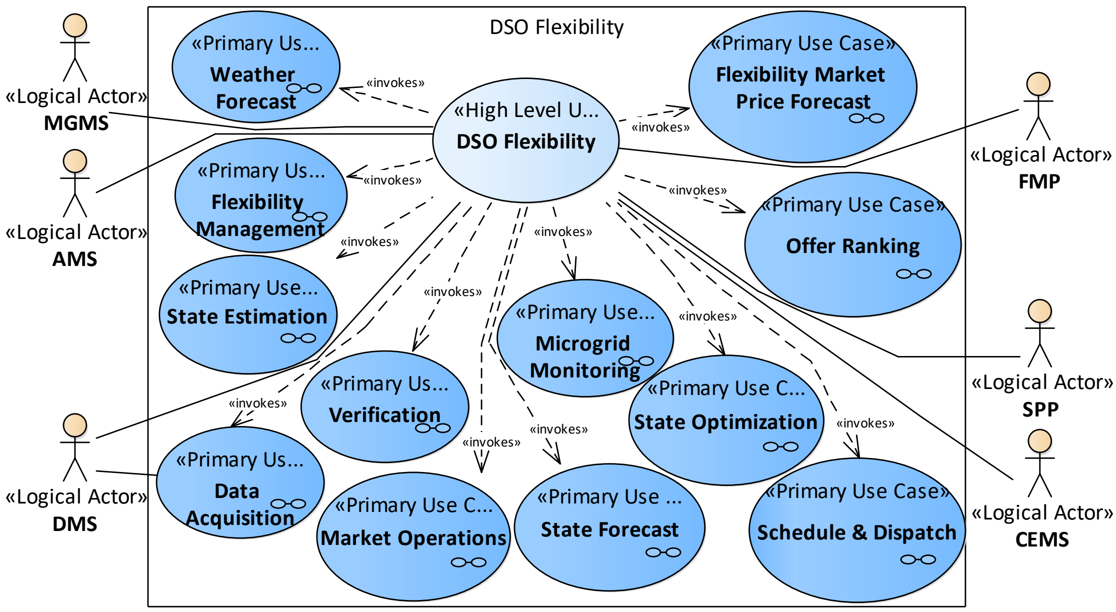


Figure 47. DSO Flexibility use case diagram.

The Microgrid Monitoring takes care of delivering measurements, operation plans and notifications to Microgrid Management System (MGMS) level for utilization in other PUCs. In addition, the Microgrid Monitoring use case clarifies communication methods and order of operations needed for execution in the DSO Flexibility use case. Other PUCs provide functionalities needed in course of the DSO Flexibility and their detailed examination are out of scope of this thesis.

Table 7. Logical actor descriptions.

Actor	Type	Description
Intelligent Electronic Device (IED)	Device	A microprocessor-based controller, smart meter or general device for control & monitoring.
Customer Energy Management System (CEMS)	IT System	A generic information system for monitoring and control of customer side's flexible resources that optimizes their consumption and generation portfolios to sell this flexibility to upwards stakeholders.
Service Provider Platform (SPP)	IT System	A system that provides the forecasts of weather and prices of flexibility market.
Aggregator Management System (AMS)	IT System	A system that acquires and processes flexibility information of Microgrids and other controllable resources on different time-scales to propose flexibility services on markets or to upwards actors and provide the management of such services.
MicroGrid Management System (MGMS)	IT System	A system that aggregates and processes technical information about Microgrid for different time periods to optimize scheduling of its resources in order to guarantee quality of supply as well as to allow maximum participation of Microgrid's resources in flexibility services.
Flexibility Market Platform (FMP)	IT System	A system for trading of flexibility between Aggregators and other market actors.
Distribution Management System (DMS)	IT System	A collection of applications within the system designed to use Microgrids' flexibility for the support of the quality of supply of distribution network.

5.1.1 Business layer

The Aggregator acts as medium between the FMO and actors providing flexibility similarly to the DREAM and IDE4L architectures. The FMO links the Aggregator and DSO as in the IDE4L. Furthermore, the Microgrid Operator (MO) manages certain part of Prosumers network. Figure 48 presents business use case overview for the analyzed use cases. Moreover, the figure illustrates business actors, business cases, business goals, use cases and relations between them.

By utilizing flexibility, the DSO may improve power quality, performance indexes and efficiency in distribution network, thus benefiting economically. Furthermore, by utilizing flexibility the DSO may have access to local control indirectly as it may send commands to other actors systems. The Aggregator may do business by providing flexibility and promote green choices and efficiency. By providing flexibility, the Prosumer may decrease payback time of equipment, have access to energy market and reduce carbon footprint. Additionally, the MO, Service Provider and FMO may provide services that support use of flexibility and/or expand their businesses.

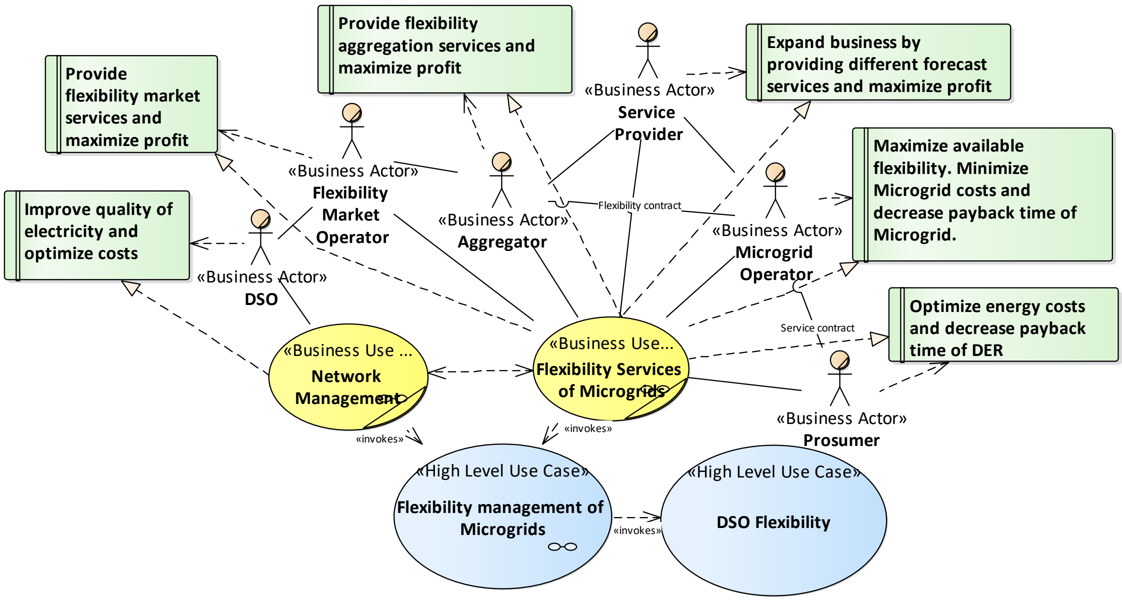


Figure 48. DSO Flexibility business case overview.

Business Use Cases (BUC) Flexibility Services of Microgrids and Network Management accommodates motives and business goals for cooperation for different actors. HLUC Flexibility management of Microgrids, which is superior to similar use cases as the DSO Flexibility, invokes the DSO Flexibility as shown in the figure. The Aggregator and MO have a contract so the Aggregator offers products that the MO possesses and both benefit in terms of money. The MO can be a company or a housing condominium, for example, or any party equivalent to them who has electrical equipment interconnected to the system and they are managing the equipment. In case the Prosumer has required capability, it can take on roles of the MO and Aggregator. Figure 49 illustrates the business layer for the use cases.

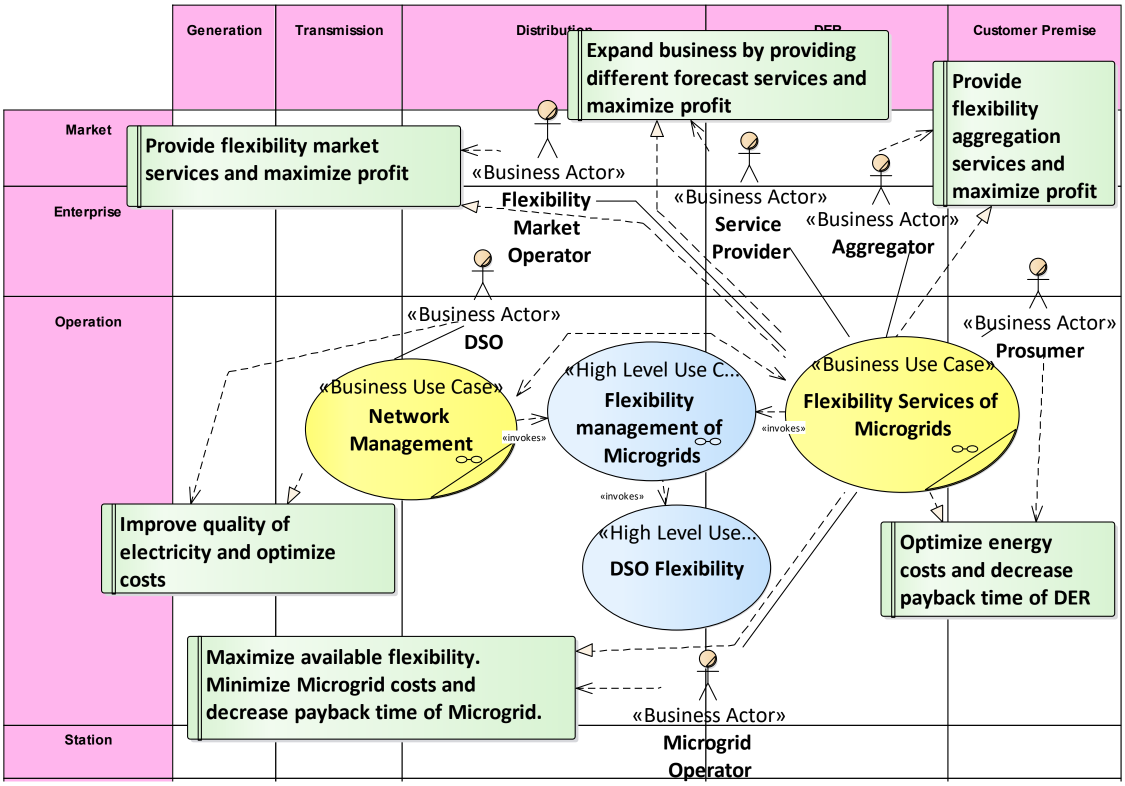


Figure 49. The business layer.

As shown in the figure, the FMO business actor sits on the Distribution domain since only flexibility market for DSO is considered. Similarly, the Service Provider business actor is located in the DER domain and market zone because it provides local weather and flexibility price forecasts.

5.1.2 Function layer

The DSO Flexibility use case and all of the PUCs on the function layer locate on the function layer as Figure 50 illustrates. Furthermore, red lines indicate function interrelation. Positions for Market Operations, Data Acquisition, State Optimization and Schedule & Dispatch are same as in similar functions from the IDE4L function layer. Moreover, positions for State Estimation and State Forecast are same as in the IDE4L. Function positioning especially promotes decentralized data acquisition and control instead of traditional decentralized data acquisition and centralized control. However, it is not a requirement.

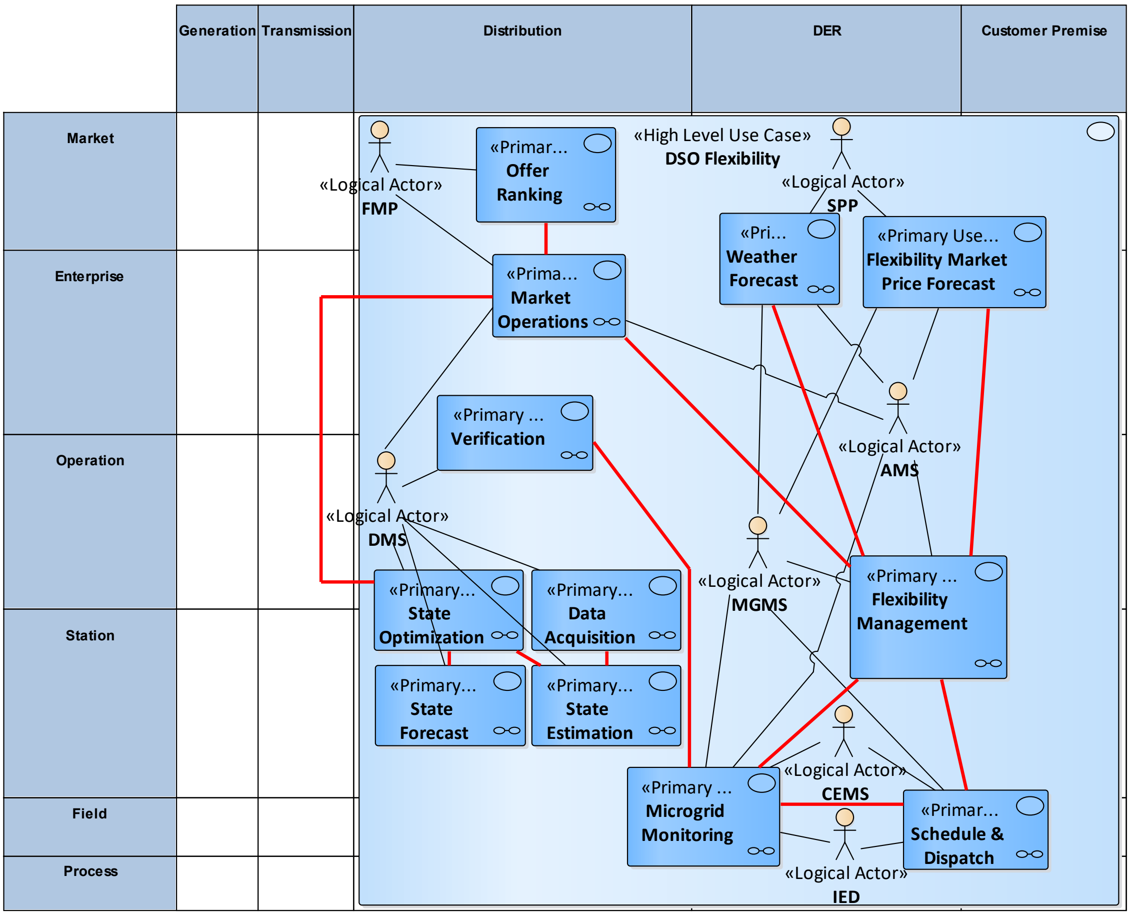


Figure 50. The function layer.

As shown in the figure, the Flexibility Market Price and Weather Forecasts use cases locate in Market/Enterprise zone as the SPP manages both of them. The Offer Ranking and Verification locate on the Market and Operation/Enterprise zones as FMP and DMS invoke them. Additionally, the Flexibility Management and Microgrid Monitoring use cases locate on border of several zones and connect various equipment in multiple domains.

The Microgrid Monitoring takes care of delivering measurements, operation plans and notifications to MGMS level for utilization. Data Acquisition provides measurements and states to DMS with DSOs own equipment. The Market Operations enables interaction between the DMS, AMS and FMP. Moreover, it covers participation to different markets, for example Day Ahead and Intraday markets. The Offer Ranking in the FMP organizes offered flexibility and ensures cost-effective use of offered power. With the State Optimization, the DSO defines required amount of flexibility. The Flexibility Management utilizes different forecasts, covers optimization tasks to calculate flexibility offers for different markets, and schedules resources when offers are accepted. The Flexibility Market Price, Weather and State Forecast and Schedule & Dispatch to some extent, provide estimations so other use cases may utilize them and allow more consistent and efficient operation of the grid. The State Estimation provides information when to activate flexibility products. The Verification confirms that purchased product was activated and may be utilized for commercial purposes too. Appendix 7 presents sequence diagrams with information objects (IO) for the DSO Flexibility and Microgrid Monitoring use cases.

5.1.3 Component layer

Before forming the component layer and placing logical actors' hardware on it, an actor mapping model needs to be done. The actor mapping model presents relations between the business actors, logical actors, software and hardware components. Figure 51 presents the actor mapping model for logical actors.

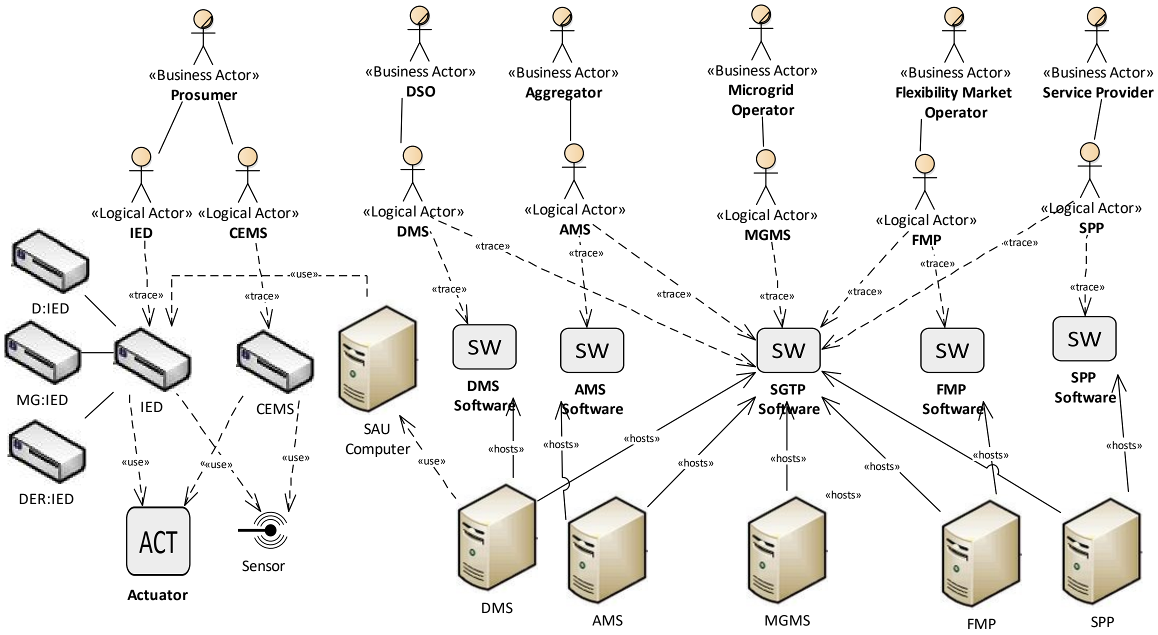


Figure 51. Actor mapping model.

As shown in the figure, all logical actors with software components have their own and SGTP related software. Moreover, relations between DMS, SAU Computer and IED are simplified in comparison to the IDE4L project.

Before placing components on the information and communication layers and presenting ICT architecture, a more practical presentation with component layer is dealt with. Components of the MultiPower laboratory test setup and other actors' components for the DSO Flexibility use case locate on the component layer as Figure 52 displays. Blue and red line indicate ICT and electrical connection, respectively. In addition, the Actuator represents a circuit breaker that the IED manages in the MultiPower.

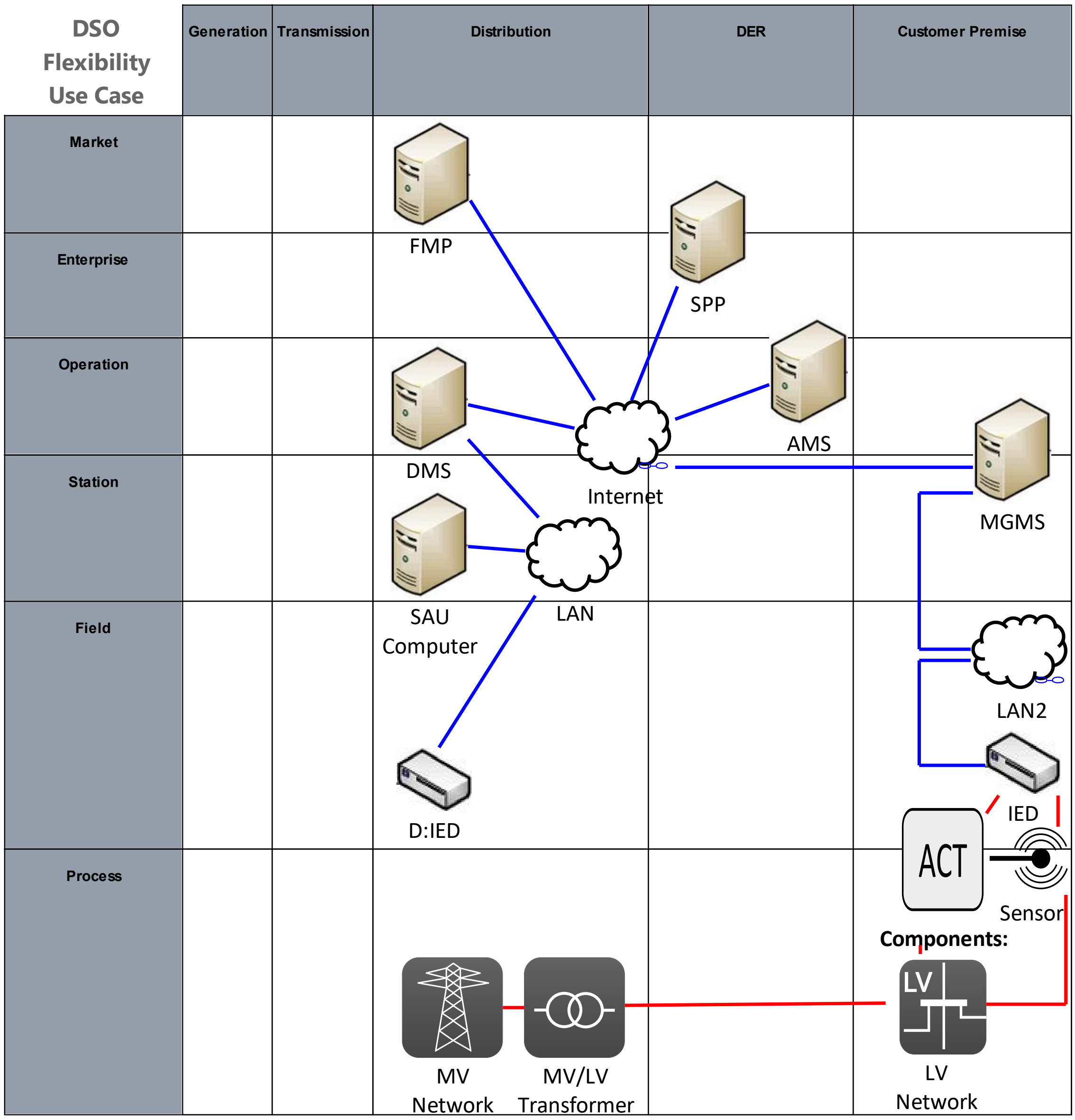


Figure 52. The component layer.

The present equipment test setup in the MultiPower conveys measurements and statuses from IEDs to MGMS level every time they are updated. Furthermore, the system conveys messages further from MGMS level after chosen period of time, certain activity or on request. With this setup the MGMS first stores information to in-memory and later dumps it to disk if one of the time and number of key changes conditions are true. All other equipment locate on different laboratories and pilot sites all over Finland except FMP.

5.1.4 Information layer

The IOs shifting between the logical actors hardware go as Figure 53 and Table 8 presents. Furthermore, not all of the IOs refer to actual message types since some of them are clustered for illustration purposes. Downstream from the MGMS level, content of information flows depend on features of devices. Blue and black lines (solid) indicate information flow and association, respectively. In comparison to the IDE4L, now the MGMS operates between the AMS and CEMS instead of direct information exchange.

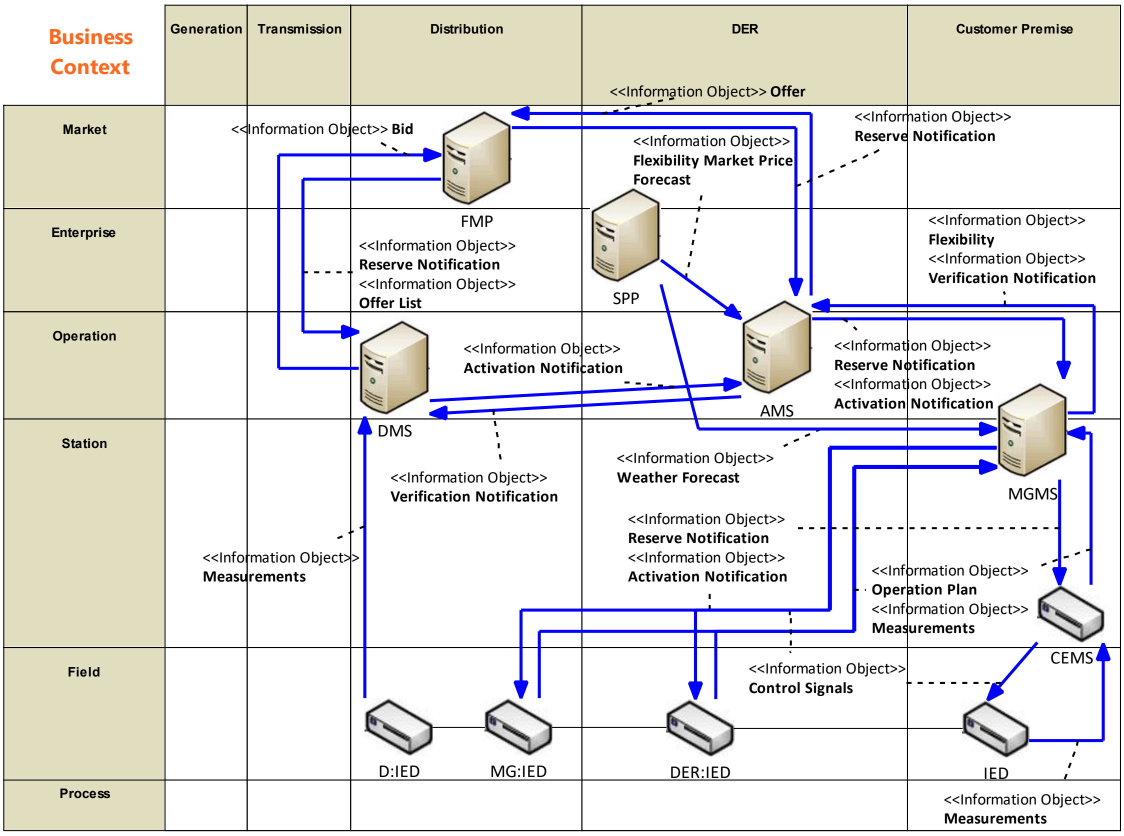


Figure 53. The information layer.

The figure displays IOs in a situation where MGMS sends flexibility information to the AMS, who then decides commercial aspects for the flexibility offer and offers it to suitable market. Therefore, with this situation the MGMS does not need price forecast from the SPP. Other option is that MGMS receives price forecast and resolves commercial aspects completely itself and then delivers flexibility information to the AMS or to the market directly. In other words, these matters highly depend on features and connections of devices and choices of the Prosumer.

Table 8. Information object descriptions.

Information object	Description
Measurements	Current and voltage measurements Apparent, active and reactive power Power factor Circuit breaker state
Control Signals	Control signal Setpoint
Operation Plan	Load/generation schedule for certain period of time
Flexibility	Offer Id, flexibility type, power, start time and stop time
Offer	Offer Id, flexibility type, power, start time, stop time, price

Offer List	Offer list. Location and price dependent
Bid	Offer Id, flexibility type, power, start time, stop time, price
Weather Forecast	Weather forecast for certain period of time
Reserve Notification	Offer Id, flexibility type, power setpoint, start time, stop time, price. Reserve notification that is provided after market clearance
Activation Notification	Offer Id, flexibility type, power setpoint, start time, stop time. Activation notification that is provided when DSO activates product
Verification Notification	Offer Id, current power setpoint. Verification notification that is provided after MGMS activates product
Flexibility Market Price Forecast	Flexibility price forecast for certain period of time

The Measurements and Control Signals IOs group different measurements, states, different control signals and setpoints, respectively. Moreover, since the SGTP uses semantic messages there is no need to separate between different message types, for example for phase and line-to-line voltage measurements, since it can be done with reference to an ontology. Figure 54 illustrates standard mapping on the information layer.

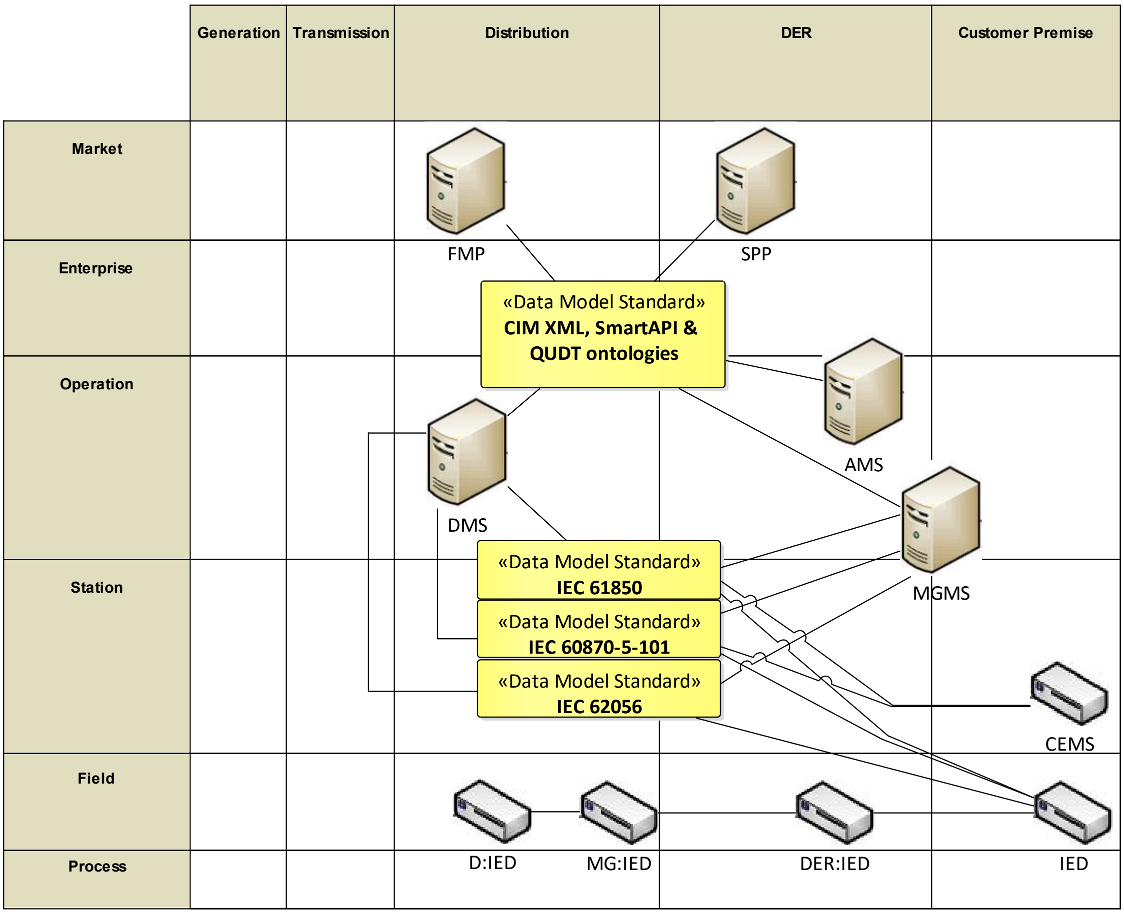


Figure 54. Standard mapping on the information layer.

5.1.5 Communication layer

Figure 55 illustrates the communication protocols between the logical actors. The SGTP uses the MQTT and HTTP in general and for connections from the field protocol is correspondent to purpose of equipment use, similarly as in the SEAS architecture. In this case, downstream from the MGMS level communication protocol is IEC 61850 MMS, IEC 60870-5-104 or DLMS/COSEM.

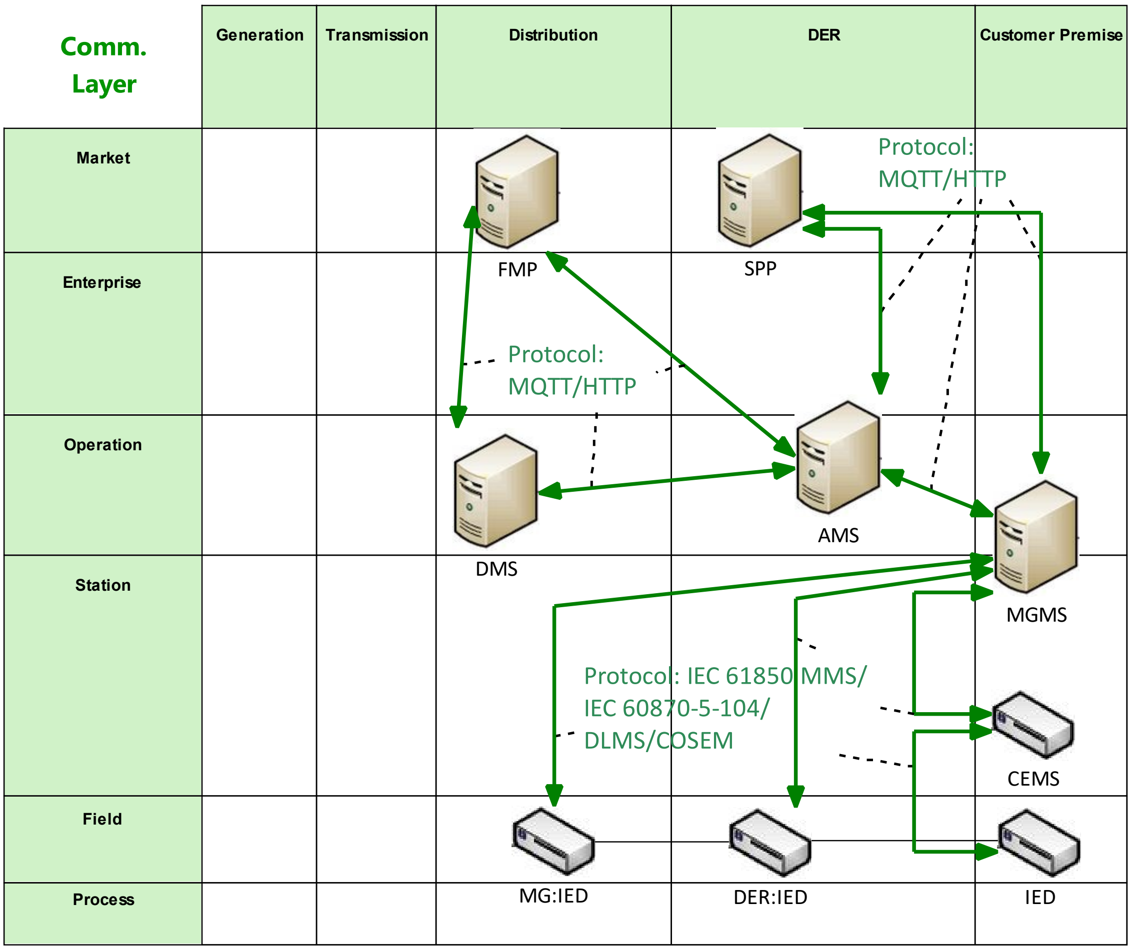


Figure 55. The communication layer.

As shown in the figure, communication protocol depends on features of the devices downstream from the MGMS level. The protocols are similar when compared to the IDE4L project. Furthermore, both MQTT and HTTP are presented as options upstream from the MGMS level now, instead of options in the IDE4L and DREAM (XMPP) projects that partly dictate format for messages. In addition, the MGMS and CEMS can be compared to GM in the SEAS architecture. As a result, the communication architecture hides legacy systems and provides flexible communication path with use of semantic data.

6. MULTIPOWER IMPLEMENTATION

This chapter presents integration task and initial test set-up in the MultiPower laboratory environment. Furthermore, this chapter provides detailed description of configuration, programming and testing activities. Development of the SGTP and its actors operations are out of the scope generally and they are utilized as they are. However, some additions were made in order to carry out tests. Figure 56 highlights the integration problem (in orange), test set-up in the MultiPower laboratory environment and parts of the SGTP (purple).

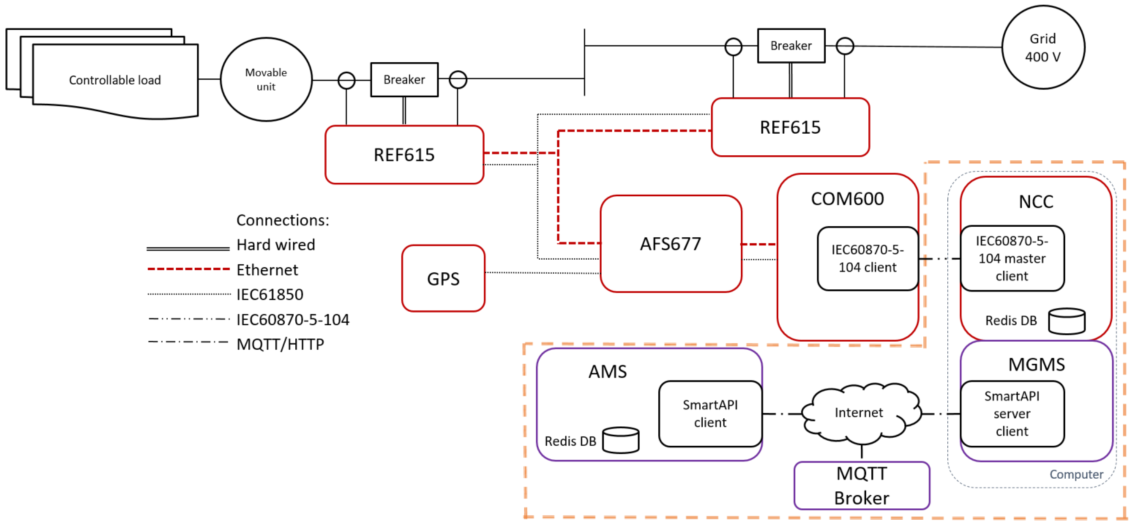


Figure 56. Test set-up and integration task (highlighted with orange triple line) within the MultiPower laboratory environment and SGTP (highlighted with purple).

As shown in the figure, the COM600 is connected to NCC via IEC 60870-5-104 client. Moreover, here the NCC is not any kind of control center and it is illustrated just to indicate link with the COM600 material. The REF615s, COM600 and Computer represents the IED and MGMS, respectively, when comparing to components in the Figure 52.

6.1 Configuration

This chapter presents configurations that were made to the computer in the MultiPower laboratory and for another computer that represents the AMS in testing.

Chosen language for testing was Python programming language. To run test scripts on the computer in the MultiPower laboratory, installing several programs on the computer was necessary. Therefore, Python release 2.7.14, Windows x86-64 version, was downloaded and installed on the computer [78]. The installer takes care of adding correct path to environment variables path, if that is selected during the installation. Execution of `python` command in command prompt confirms proper installation of the Python, as it returns the release number of the Python amongst other things.

Next, newest Microsoft Visual C++ Compiler for Python 2.7 (version 9.0.0.30729) installer was downloaded and the compiler was installed [79]. A package management system called pip was used to install rest of the things tests require. Moreover, the Python installer installed the pip as part of the Python installation. The pip downloaded and installed the SmartAPI to the computer, when current folder is C:\Python27\Scripts\ with the command prompt and it executes following command:

```
pip.exe install SmartAPI
```

Now the SmartAPI is located in Python site-packages and its modules are usable in code, if they are imported, for example. In addition, by replacing SmartAPI with web.py, paho-mqtt and redis in the command, the pip downloads and installs latest versions of them to computer. Finally, repeating configuration process for another computer is necessary in order to use it to represent the AMS in different location.

In addition, w32tm service (Windows) is used for a public Network Time Protocol (NTP) service, so the MGMS and AMS may synchronize their clocks from the same server. Both machines (the MGMS and AMS) run at least version 1607 of Windows 10 or Windows Server 2016, be no further than stratum 5 and have latency less than 5 ms, so accuracy of 50 milliseconds is achievable with this setup [80]. The VTT maintains the public NTP service and reference for it is official time in Finland [81].

6.2 Programming

This chapter presents used programming tools and relevant parts of the added code in case of particular message. First tests in the related research project, with HTTP client/server and MQTT client, were about sending hard coded voltage measurement value with single value object. That code serves as base for the solution offered for testing in this thesis. In addition, SmartAPI Python programmer guide [82] and other Python related literature offered solutions and guidance.

6.2.1 SmartAPI and Redis database

For programming purposes, a software called Eclipse Integrated Development Environment (IDE) for Java Developers, was downloaded and installed to a computer [83]. Furthermore, Eclipses integrated software installer installed Python IDE PyDev to the Eclipse, for Python code development purposes [84].

A simple menu function was added to publisher code so topics to be published can be chosen easily during tests. Program 1 presents the added function and additions to main function. The menu requests to insert “1” to add topic and accepts any other integer to quit menu.

```
def menu():
    print "(1) add topic to be published \n(x) quit"
    while True:
        try:
            action = int(input())
            return action
        except Exception:
            print "Invalid input. Only integers allowed."
def main():
    redisKeyPub = []
    while True:
        action = menu()
        if action == 1:
            taginput = raw_input("Publish topic:")
            redisKeyPub.append(taginput)
        else:
            break
```

Program 1. Simple menu to choose signal tags during tests.

In order to enable reading from the local Redis database, a module with redis-py client and several functions were created. The redis-py client is available at andymccurdy/redis-py Github page. After adding `import redis` command to code, functions of the client are available. Moreover, first line of Program 2 enables connection to local Redis server database 0 port 6379 and use of redis commands on following lines of the code. Line 2 enables use of Pipelining, which is a feature of redis, and reading replies with single command. Lines 4 to 11 define a function to read values from hashes in the local Redis server at the MultiPower and store them to a list for later use. Additionally, other similar functions were added that read different types of information from the local MultiPower Redis database.

```
1    r = redis.StrictRedis(host='localhost', port=6379, db=0)
2    pipe = r.pipeline()
3
4    def getRedisFlexibility(self, redisKey):
5       list = OrderedList()
6       list.add_items(pipe.hget(redisKey, "ID")
7               .hget(redisKey, "Type")
8               .hget(redisKey, "Power")
9               .hget(redisKey, "Start")
10              .hget(redisKey, "Stop").execute())
11      return list
```

Program 2. Redis connection establishment and value reading from the local database.

Now when the server and client can read information out of the local MultiPower Redis database with different functions, the client can create, serialize and publish an information object with code in Program 3. The program presents a function to create the information object and additions to the main function. Furthermore, lines from 4 to 26 create an entity with identifier, add a type reference to the entity and add multiple value objects with different information to the entity. Finally, lines 2-3 and 27 to 37 create a notification, serialize and publish it with QoS 1.

```
1  def createFlexibilityInfoObject(item):
2      n = NotificationFactory().create(myIdentifier)
3      activity = Activity()
4      flexibility = Entity(item)
5      flexibility.addType(NS.SMARTAPI + "Flexibility")
6      itemValue = GetRedis().getRedisFlexibility(item)
7      vo = ValueObject(dataType = NS.SMARTAPI + "string", value =
8      itemValue.get_item(0))
9      vo.setName("ID")
10     flexibility.addValueObject(vo)
11     vo = ValueObject(dataType = NS.SMARTAPI + "string", value =
12     itemValue.get_item(1))
13     vo.setName("Type")
14     flexibility.addValueObject(vo)
15     vo = ValueObject(unit = NS.SMARTAPI + "Watt", quantity = NS.SMARTAPI +
16     "ActivePower", value = itemValue.get_item(2))
17     vo.setName("Power")
18     flexibility.addValueObject(vo)
19     vo = ValueObject(dataType = NS.SMARTAPI + "dateTime", value =
20     itemValue.get_item(3))
21     vo.setName("Start")
22     flexibility.addValueObject(vo)
23     vo = ValueObject(dataType = NS.SMARTAPI + "dateTime", value =
24     itemValue.get_item(4))
25     vo.setName("Stop")
26     flexibility.addValueObject(vo)
27     activity.addEntity(flexibility)
28     n.setActivity(activity)
29     serialized = Tools().toString(n)
30     return serialized
31
32 def main():
33     while True:
34         time.sleep(5)
35         for item in redisKeyPub:
36             elif "Flexibility" in item:
37                 client.publish(item, createFlexibilityInfoObject(item), 1)
```

Program 3. Create, serialize and publish Flexibility IO.

The client (Aggregator) stores information from incoming messages (responses or publish messages from the broker) to its own Redis database. Program 4 presents code for handling and storing the information from the incoming messages to the Redis hashes and sorted sets. Additionally, the program prints timestamp when data is stored to the Redis for testing purposes.

Furthermore, the function first gets identifier from *Entity*, checks if the entity contains types and adds retrieved information to variables and hash fields. Second, the function acquires and stores names, values, unit, quantity and datatype of value objects to variables and hash fields. Finally, the function saves the hash, which contains all the information from the message, to a sorted set that arranges messages based on UNIX time. In addition, the function uses different Ids to separate same kind of information in entities. An entity might have type references, for instance, to the Smart API or CIM ontologies.

```
def setRedisInfo(self, resp):
    if res.firstActivity().hasEntity():
        for entity in res.firstActivity().getEntities():
            if entity.hasIdentifierUri():
                redisKey = entity.getIdentifierUri()
                redisId = str(r.incr(redisKey + ":Id"))
                if entity.hasType():
                    redisTypes = entity.getTypes()
                    for types in redisTypes:
                        redisTypeId = str(r.incr(redisKey + ":" + redisId + ":TypeId"))
                        pipe.hset(redisKey + ":" + redisId, "EntityType" + redisTypeId, types)
            if entity.hasValueObject():
                for vo in entity.getValueObjects():
                    if vo.hasName() and vo.hasValue():
                        variant = vo.getValue()
                        redisValue = variant.getValue()
                        redisName = vo.getName()
                        pipe.hset(redisKey + ":" + redisId, redisName, redisValue)
                        if vo.hasUnit():
                            redisUnit = vo.getUnit()
                            pipe.hset(redisKey + ":" + redisId, redisName + ":Unit", redisUnit)
                        if vo.hasQuantity():
                            redisQuantity = vo.getQuantity()
                            pipe.hset(redisKey + ":" + redisId, redisName + ":Quantity", redisQuantity)
                        if  vo.hasDataType():
                            redisDatatype = vo.getDataType()
                            pipe.hset(redisKey + ":" + redisId, redisName + ":Datatype",
                            redisDatatype)
            unixTime = time.time()
            pipe.zadd("events:" + redisKey, unixTime, redisKey + ":" + redisId).execute()
            print redisKey, datetime.utcnow()
        return
```

Program 4. Redis message storing with hashes and sorted sets.

As shown in the program, it saves semantic information from the message with a hash and sorts out order when messages arrived with a sorted set. Again, the function utilizes Pipelining, which enables storing data to redis in specific order when executed. As a result, this structure enables storing of information object and time series data.

6.2.2 IEC 60870-5-104 client

The computer in the MultiPower has a software called Visual Studio 2017 installed to it, so running and modification of the IEC 60870-5-104 client are possible. Minor modifications to the client were made with the Visual Studio in order to remove modification of the measurements and store them as they are. The client is written in C# programming language.

The client modifies CP56Time2a timestamp to UNIX-time and quality information to “0” or “1”, so these functions were simply removed from the client’s code to retain and store original information to the local Redis. Additionally, separate time synchronization from the client was removed.

6.3 Testing and results

This chapter presents testing activities and results. Testing covers transferring use case related messages between the MGMS and AMS and controlling process. Furthermore, for the DSO Flexibility use case only steps 5 and 25-28 in Appendix 7 are considered as part of the tests since actor processes are not developed yet within the SGTP. However, it confirms proper equipment operation in the MultiPower. Finally, comparison to technical requirements in the use cases is conducted.

6.3.1 Basic operation

First, topic for certain feeders' flexibility information was added to a list to be published by MGMS with QoS 1. Second, the AMS subscribed to all flexibility topics from MultiPower with # wildcard with following commands:

```
mqtt_topic=” http://vtt.fi/Flexibility/#”
agent=EventAgent(on_notification,mqtt_topic=
mqtt_topic)
agent.connect()
```

As soon as the AMS subscribed to all Flexibility topics, it started receiving messages from the MGMS via the MQTT broker. During tests, the Aggregator can verify that the client receives and stores messages properly with a separate Redis client. Figure 57 and Figure 58 present screenshots of the Redis client with query results of Flexibility information for a certain feeder from the AMS database. The SmartAPI ontologies were used as references in the messages as shown in the Figure 58.

Figure 57. Query results for "events:http://vtt.fi/Flexibility/JK-T.KK-TL3" sorted set from the AMS database.

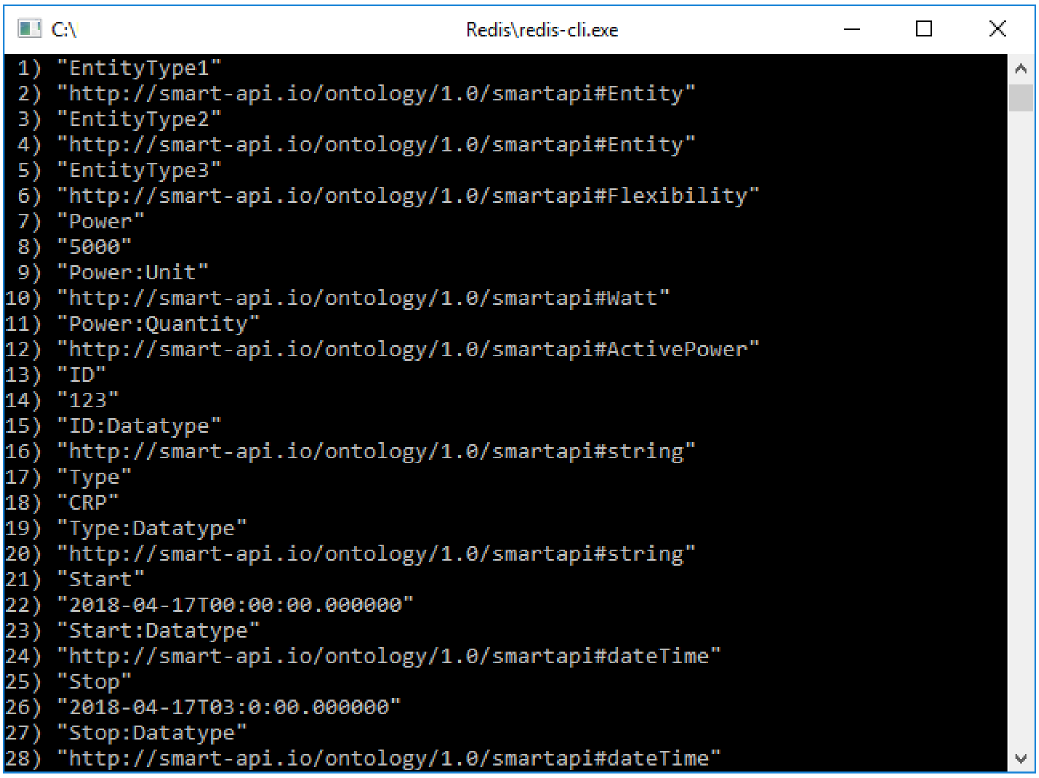


Figure 58. Query results for "http://vtt.fi/Flexibility/JK-T.KK-TL3" hash from the AMS database.

DSO Flexibility test started from sending Flexibility IO to AMS and continued with receiving *ActivationNotification* IO from AMS as MGMS. *ActivationNotification* IO lead to a control command that the IEC 60870-5-104 client eventually sent to the COM600. Then, confirmation that field devices operated correctly, was collected from circuit breaker status information in the COM600. Similarly as before, with a separate Redis client the MO can monitor the value of control command information in its database and simultaneously observe the changes in the field process. Next paragraph presents details about timeframes that tested actions took to perform.

6.3.2 Technical requirements

Use cases contain technical requirements for transfer time, rate, synchronization accuracy and availability. Table 9 presents the technical requirements with functional and technical references.

Table 9. Use case technical requirements.

Transfer time class	**Transfer time (ms)**	**Functional reference**	**Technical reference**
TT0	> 1000	Files, events, log contents	
Transfer rate class	**Transfer rate (kb/s)**	**Functional reference**	**Technical reference**

TR4	1000			
Synchronization accuracy	**Synchronization accuracy (ms)**		**Functional reference**	**Technical reference**
SA4	100			NTP over public Internet
Availability class	**Value (%)**	**Downtime (min/a)**	**Functional reference**	**Technical reference**
A0	99,5	2628		Typical Internet access

Requirements for synchronization accuracy and availability are met because of the system setup described previously in this chapter and since offsets to NTP reference clock are less than 35 ms in both computers. Transfer rate requirement is also fulfilled since the internet connection rates at least 100/100 Mbit/s on several public tests. In addition, requirement for the transfer time is fulfilled as messages are transferred between actors. However, transfer times were gathered in order to gain supplementary information how system performs and to compare to previous results. Table 10 presents average transfer times with 10 attempts between REF615 and MGMS database and between the MGMS and AMS databases for different messages in monitoring and control direction. Appendix 8 presents full list of testing results. Information and timestamp that the JK-T.KK-TL3 circuit breaker position command was executed properly were gathered from JK-T.KK-TL3 circuit breaker position status in COM600 so transfer time in that case is pessimistic.

Table 10. Transfer times.

Monitoring direction			
Message and route	Flexibility, AMS database ← MGMS database		Feeder phase voltage, MGMS database ← REF 615
Protocol	HTTP	MQTT	IEC 60870-5-104
Transfer time (ms)	47	52	483
Control direction			
Message and route	ActivationNotification, AMS database → MGMS database		Feeder JK-T.KK-TL3 circuit breaker position, MGMS database → REF 615
Protocol	MQTT		IEC 60870-5-104
Transfer time (ms)	36		584

As shown in the table, test results for transfer times with IEC 60870-5-104 client in monitoring direction (483 ms) were much better than in previous work (7 and 33 seconds). The fact that only few timestamps were gathered during previous testing might be the reason for this significant difference in test results. Moreover, if the client is running just briefly, it will most likely receive old information instead of new, because the information is updated at certain intervals.

7. CONCLUSIONS

Increasing use of RES drive towards the Smart Grid globally and on EU level. The Smart Grid differ in many ways from the traditional grid. Differing characteristics include for instance two-way real-time communication, distributed power generation, dispersed network, large volumes of data, automatic monitoring and control, security and privacy issues, use of storage systems and great amount of user choices. Even the Smart Grid is widely studied there is potential for development, for example, in interoperability, control and context-awareness.

In this thesis, architecture model for the SGTP and integration of the MultiPower laboratory environment to the SGTP were presented. For the architecture model the HEILA methodology, which bases on the SGAM Framework and use cases, was utilized. The methodology takes into consideration related architecture descriptions, use cases, and allows iteratively build and present design from architectural viewpoints.

The produced architecture model and description presents with five different layers how Prosumer, MO, Aggregator, DSO, Service Provider and FMO from the DSO Flexibility HLUC and Microgrid Monitoring PUC work together to benefit from flexibility related services. The architecture model also shows functional requirements and ICT architecture for the use cases. Furthermore, links and similarities to related architecture descriptions in SEAS, IDE4L and DREAM projects are pointed out. Additionally, the component layer in case of use case realization with the MultiPower laboratory was presented.

The architecture model increases level of details and adds system specific information when comparing to the SEAS architecture, which presents architecture in a way that is more general. The architecture model also builds microgrid related functionalities on top of the IDE4L architecture and adds MQTT protocol and self-descriptive messaging with utilization of Smart API. Similarly, with utilization of the Smart API self-descriptive messaging is added to communication between actors when compared to the DREAM architecture and use of MQTT protocol instead of XMPP protocol, for example. This way messaging is more flexible, the messages are not bound to any particular format and new additional services can be developed in way that is more straightforward. The function positioning with two-way communications in the architecture promotes decentralized data acquisition and control instead of traditional decentralized data acquisition and central control. That may ease market integration, privacy, autonomy and scalability issues as discussed in the DREAM project. Additionally, the architecture hides legacy systems. As a result, the architecture may promote development and utilization of flexibility related services and products. However, it should be noted that the architecture model have to be further developed in case of other use cases. Moreover, IOs should be added to the standard mapping on information layer of the model since it would increase level of details and decrease possibility of misinterpretation.

The MultiPower laboratory environment was integrated with present version of the SGTP as existing equipment in the MultiPower can be monitored and controlled with the system. Although, the SGTP is at early stage of development, so when it is further developed and additions are made, also connection with the MultiPower should be revised and further developed.

The integration included configuration of the computer in the MultiPower, programming functions that read, write and deliver information within the system and simple tests with another computer to demonstrate operation with the SGTP and to compare test results to the technical requirements in the use cases. Furthermore, the function that stores information to the Aggregators database allows saving of the semantic information and time series data. At connection point, the MultiPower equipment uses Redis as database to store information. Moreover, the IEC 61850 and IEC 60870-5-101 information models and IEC 60870-5-104 protocol are used internally for communication. For external communication Smart API and QUDT ontologies, MQTT and HTTP protocols with semantic information are exploited. The CIM was not utilized at this point.

Because of development stage of the SGTP, only relatively small part of the DSO Flexibility HLUC was tested. Nevertheless, tests demonstrate that the process on field can be controlled with the system as result of to be developed actor processes. Additionally, tests provide overall and section delay information that can be taken into account when designing processes within the system with different time scales or new use cases.

In further research work in HEILA project, necessary security measures and enhancements to server and client code (e.g. message encryption), validation and possible utilization of CIM should be considered. In the MultiPower laboratory EMS, different type of controllable load and DER, which are more suitable for routine-testing activities, should be considered to enable tests that are more versatile.

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APPENDIX 1: USE CASE: MONITORING TEMPLATE

1 Description of the Use Case

Name of Use Case

Real - time monitoring of Microgrids by Aggregator (RTMM)

Version Management

Changes / Version	***Date***	***Name Author(s) or Committee***	***Domain Expert*** Primary, additional	***Area of Expertise / Domain / Role***	***Title***	***Approval Status*** *draft, for comments, for voting, final*
Version 0.1: Technical part of the use case	17.11.2017	Author: Aleksei Mashlakov (LUT) Reviewers: Ville Tikka Samuli Honkapuro	Primary	Energy experts, core team	First draft	Draft for comments
Version 0.2: Revised version of 0.1 (adjusted terminology and architecture)	04.01.2018	Aleksei Mashlakov (LUT)	Primary	Core team	Second draft	Draft for review
Version 0.3: Addition of further details and workflows to the use case.			Primary	IT experts		

Basic Information to Use Case

Relation to Higher Level Use Case	
Cluster	***Higher Level Use Case***
Monitoring	Flexibility management of Microgrids

Maturity of Use Case
Under development
Prioritization
High
Generic, Regional or National Relation
Generic
View - *Technical / Business*
Technical
Further Keywords for Classification
Real-time monitoring

Scope and Objectives of Use Case

Scope of Function
The use case consists in monitoring aggregated market data of Microgrids by Aggregator. The data include supply and demand flexibility potential at the point of common coupling (PCC) on different time scales. Monitoring of detailed technical data within Microgrids by Aggregator is out of the scope of this use case.
Objectives of Function
This monitoring data are needed by Aggregator to estimate the available flexible resources that could be offered to the flexibility or reserve markets to maximize financial profits of Microgrids's flexibility.

Narrative of Use Case

Short description – *max 3 sentences*
Monitoring for the Aggregator is performed by subscription to the updates of aggregated flexibility potential of Microgrids for different time periods. Aggregator then harmonizes these real-time and forecasted data to use them on flexibility/reserve markets with maximum financial profit. "Real-time" in this context could mean something in between 1 millisecond and some minutes (soft real-time).
Complete description
Accurate monitoring and forecasting of Microgrid's flexibility are the basic processes for Aggregator that allow him to achieve sustainable business profit on flexibility/reserve markets by: • Composing right market strategy • Decreasing the amount of electricity imbalance • Verification of the contract promises • Sharing the income between the participants in a fair way This use case presents the required interfaces for operation of the RTMM. Aggregator presented in this interface by aggregator management system (AMS) directly interacts only with microgrid management systems (MGMSs) from where it receives new published reports with necessary data, processes them, and utilizes it for DMS/TSO EMS verification or flexibility/reserve market bids. Data considered by the use case are: • Real-time and Forecasted values of supply and demand flexibility potential (every cycle ~ 15 min) for market planning • Real-time data used for verification of control commands/frequency regulation The data publishing of MGMS can happen periodically, based on event/threshold crossed or request. The first two subscription triggers can complement each other if operating together (e.g. if data sharing every minute, the event update can happen during this minute).

Actors: Detailed Terminology

Actor Name	***Actor Type***	***Actor Description***	***Further information specific to this Use Case***
AMS	System	Aggregator Management System	
AMS.DM	Function	Aggregator Management System Data Management	
AMS.DBM	Function	Aggregator Management System Data Base Management	
AMS.DA	Function	Aggregator Management System Data Acquisition	
AMS.DP	Function	Aggregator Management System Data Processing	
DMS	System	Distribution Management System	
DMS.DA	Function	Distribution Management System Data Acquisition	
MGMS	System	Microgrid Management System	
MGMS.DM	Function	Microgrid Management System Data Management	
MGMS.DBM	Function	Microgrid Management System Data Base Management	
MGMS.DT	Function	Microgrid Management System Data Transmission	
MGMS.FO	Function	Microgrid Management System Flexibility Optimization	

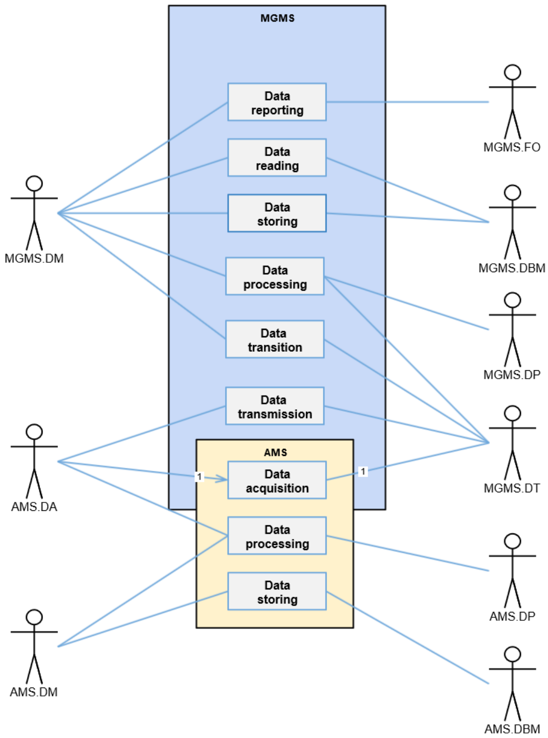
Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	***Impact of Issue on Use Case***	***Reference*** *– law, standard, others*
Customer-owned distributed energy resources (DERs) information	Data from customer-owned DERs is required as input of the AMS. Pre-condition: MGMS has all the rights/contracts to **share** internal data to AMS.	

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/Contract	***Triggering Event***	***Pre-conditions***	***Assumption***	**Post-conditions**
AMS		The system is up and running.		
MGMS		The system is up and running.		

2 Drawing or Diagram of Use Case



3 Step by Step Analysis of Use Case

Scenatio No.	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
1.NS1: Time based report from MGMSs	MGMS	Periodically data report is generated by MGMS and delivered to AMS.	AMS has subscribed for flexibility updates of MGMS.	The data about potential flexibility of Microgrids is stored in AMS.DB.
2. AS1: Event based report from MGMSs	MGMS	Event based data report is generated by MGMS and delivered to AMS.	MGMS settings includes monitoring of threshold values and event report.	The data about potential flexibility of Microgrids is stored in AMS.DB.
3. AS2: Request from AMS	AMS	AMS requests a data report from MGMS.	Request - response communication is settled between MGMS and AMS.	The data about potential flexibility of Microgrids is stored in AMS.DB.
4. AS3: Report from MGMSs failed	AMS	No data were acquired after a timeout or request.	Request was sent to MGMS or timeout is settled in case of subscription.	The data about potential flexibility of Microgrids is **not** stored in AMS.DB.

Steps – Normal Sequence

Scenario Name :			*1.NS1: Time based report from MGMSs*				
Step No.	***Event***	***Name of Process/Activity***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
*Confirmation messages are currently not included in the scenario							
1	Periodically	Data reporting	MGMS.FF transmits an updated report to MGMS.DM	MGMS.FF	MGMS.DM	Volume of real-time and forecasted flexibility potential of Microgrid (min bid activation)	
2	Report is ready	Data transfer	MGMS.DM transfers a report to MGMS.DT	MGMS.DM	MGMS.DT	Microgrid ID, Security level, Priority, Volume of real-time and forecasted flexibility potential of Microgrid (min bid activation)	
3	Report is delivered to MGMS.DT	Data acquisition	MGMS.DT publishes a report to AMS.DA	MGMS.DT	AMS.DA	Microgrid ID, Volume of real-time and forecasted flexibility potential of Microgrid (min bid activation)	TT0, TR4, SA4, A0
4	Report is acquired by AMS.DA	Data transfer	AMS.DA transfers an input data to AMS.DP	AMS.DA	AMS.DP	Microgrid ID, Volume of real-time and forecasted flexibility potential of Microgrid	TT0, TR4, SA4, A0

5	Report is delivered to AMS.DP	Data validation	AMS.DP "check routines", that check for correctness, meaningfulness, and security of data that are input to the system.	AMS.DP	AMS.DP	No information exchange	
6	Report is processed by AMS.DP	Data transfer	AMS.DP returns the processed data to AMS.DA	AMS.DP	AMS.DA	Mapping plan, Input data	TT0, TR4, SA4, A0
7	Report is delivered to AMS.DA	Data transfer	AMS.DA transfers the processed data to AMS.DBM	AMS.DA	AMS.DBM	Input data	
8	Report is delivered to AMS.DBM	Data storing	AMS.DBM stores the report checked by AMS.DP	AMS.DBM	ASM.DB	Input data	

Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name :			*2. AS1: Event based report from MGMSs*				
Step No.	***Event***	***Name of Process/Activity***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
2a1	Threshold is crossed	Data transfer	MGMS.DM transfers a report to MGMS.DT	MGMS.DM	MGMS.DT	Microgrid ID, Security level, Priority, Volume of real-time and forecasted flexibility potential of Microgrid (min bid activation)	

Scenario Name :			*3. AS2: Request from AMS*				
Step No.	***Event***	***Name of Process/Activity***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
1-2a1	AMS needs data and asks it from MGMS	Data request	AMS.DA requests a data report from MGMS.DT	AMS.DA	MGMS.DT	Request signal	
1-2a2	Data are processed	Data request	MGMS.DT requests FlexReport from MGMS.DM	MGMS.DT	MGMS.DM	Request signal	
1-2a3	Request was acquired	Data retrieving	MGMS.DM retrieves the data from MGMS.DBM	MGMS.DM	MGMS.DBM	Volume of real-time and forecasted flexibility potential of Microgrid (min bid activation)	

Scenario Name :			*4. AS3: Report from MGMSs failed*				
Step No.	***Event***	***Name of Process/Activity***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
3a1	An error occurred between end points	Data acquisition fails	MGMS.DT could not transmit a report to AMS.DA	MGMS.DT	AMS.DA	NONE	
3a2	No data about Microgrid is received	Data notification	AMS.DA notifies AMS.DT that some microgrid has not respond	AMS.DA	AMS.DT	Notification, Microgrid ID	
3a3	Notification is acquired	Data acquisition	AMS.DT sends request to AMS.DA	AMS.DT	MGMS.DA	State request	

APPENDIX 2: USE CASE: DSO FLEXIBILITY TEMPLATE

1 Description of the Use Case

Name of Use Case

DSO requests flexibility service (from the viewpoint of MO)

Version Management

Changes / Version	***Date***	***Name Author(s) or Committee***	***Domain Expert*** Primary, additional	***Area of Expertise / Domain / Role***	***Title***	***Approval Status*** *draft, for comments, for voting, final*
Version 0.1	21.11.2017	Author: Matti Aro (VTT)	Primary	Power grid operations	First draft	Draft for review
Version 0.2 Revised version of 0.1 (adjusted terminology and architecture)	5.1.2018	Matti Aro (VTT)	Primary	Core team	Second draft	Draft for review
Version 0.3 Changes based on reviews	18.1.2018	Matti Aro (VTT)	Primary	Core team	Third draft	Draft for review
Version 0.4 Harmonizing Detailed UC with sequence diagram	22.3.2018	Matti Aro (VTT)	Primary	Core team	Fourth draft	Draft for review

Basic Information to Use Case

Relation to Higher Level Use Case	
Cluster - Monitoring, control, market	***Higher Level Use Case***
Control	Flexibility management

Maturity of Use Case *– in business operation, realized in demonstration project, , realised in R&D, in preparation, visionary*
Under development
Prioritisation
High
Generic, Regional or National Relation
Generic
View *- Technical / Business*
Technical
Further Keywords for Classification
Power quality, flexibility services, microgrid management, distributed energy resources

Scope and Objectives of Use Case

Scope of Function
This use case is part of a more general scheme which aims at creating a Data Exchange Platform for managing Distributed Energy Resources. This use case demonstrates how Microgrid Operator (MO) interacts with Aggregator to provide its flexible resources to flexibility market.
Objectives of Function
MO's objective here is to optimally schedule its own resources within Microgrid to achieve maximum flexibility volume to be offered to Market Place via Aggregator, while still maintaining the quality of supply.

Narrative of Use Case

Short description *– max 3 sentences*
This use case demonstrates how MO interacts with Aggregator to provide its flexible capacity to flexibility market.
Complete description
This use case presents the required interfaces for MO to successfully act as a flexible resource provider at flexible markets. The main functionality of acting as a flexible resource holder for MO is to gain profit by using its resources the most optimal way. Loop 0*: MO optimizes its own flexible resources with weather forecasts provided by SP so that a maximum possible amount of flexible resources is available for flexible market. MO then creates an offer where it lists its available resources and minimum price for the use of it and sends it to Aggregator. → When some of MO's bids get accepted, MO receives information about that from Aggregator and stays ready if the regulation if activated (Conditional Re-Profiling). If and when regulation is activated, MO receives info about that from Aggregator and sends control commands to DERs. After the regulation MO sends verification of the successful regulation to Aggregator

Actors: Terminology

Actor Name *see Terminology List*	***Actor Type*** *see Terminology List*	***Actor Description*** *see Terminology List*	***Further information specific to this Use Case***
Sensor	Device	Sensor	A device that monitors some variable (e.g. voltage, current, battery level, temperature etc.)
MGMS	System	Microgrid Management System	A system that acquires data about real-time state of grid nodes (V, I, cos fii) and DERs (available kW, kWh and forecast of future) and enables the control of DERs for flexibility operation. Also clusters and processes the data and publishes it for other parties to use it (Aggregator etc.)
MGMS.DA	Function	Microgrid Management System Data Acquisition	A system that receives data from microgrid sensors and sorts it to clusters and processes the data into an agreed format
MGMS.DP	Function	Microgrid Management System Data Processing	A function that processing the data and generates a report.
MGMS.DT	Function	Microgrid Management System Data Transmission	A function that reports updates of data to AMS.DA in relevant format.
MGMS.DM	Function	Microgrid Management System Data Management	It represents the storage system of MGMS.
MGMS.SF	Function	Microgrid Management System State Forecasting	A function that forecasts the state of Microgrid on different time frames based on the data from IEDs (P,Q, U, I) and CEMSs (flex P, Q)
MGMS.TS	Function	Microgrid Management System Trading System	A function that defines aggregated price sensitivity for the optimized flexibility based on the offers of CEMSs, divides the revenue between all DERs that were participating in the flexibility service and those that were utilized for the maintaining of the required quality levels to gain more flexibility available.
AMS	System	Aggregator Management System	A system that collects and stores flexibility potential information of Microgrids as well as reports aggregated data to DMS proposing flexibility services. It is also responsible for the implementation of closed deals.
AMS.DA	Function	Aggregator Management System Data Acquisition	A function that acquires control commands and state information from DMS.DT and MGMS.DT for AMS.DP to process it.
AMS.DM	Function	Aggregator Management	It represents the storage system of AMS.

AMS.DT	Function	Aggregator Management System Data Transmission	A function that writes a price - curve report for flexibility activation of each microgrid to DMS.DA as well as notifies DMS.DA about validation of resource activation.
IED	Device	Intelligent Electronic Device	Microprocessor-based controller, for example circuit breaker
SP	System	Service Provider	Service Provider is a third-party actor providing information, e.g. weather or price forecasts
CEMS	System	Customer Energy Management System	A system that is responsible for energy management in some microgrid subsystem, e.g. household or small industry

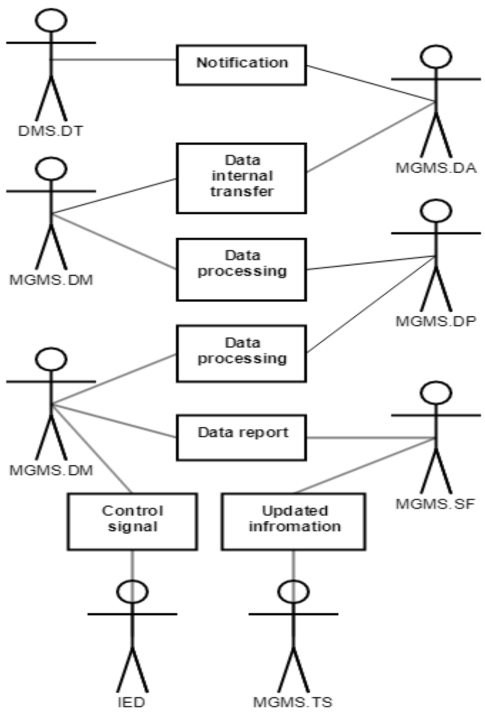
Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	***Impact of Issue on Use Case***	***Reference** – law, standard, others*
Customer-owned distributed energy resources (DERs) information	Data from customer-owned DERs is required as input of the MDXP.	

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/Contract	***Triggering Event***	***Pre-conditions***	***Assumption***	**Post-conditions**
MGMS		The system is up and running		
AMS		The system is up and running		

Diagram of Use Case



3 Step by Step Analysis of Use Case

Scenario No.	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
Primary scenario 1	MO	Bid is accepted on the flexibility markets (in whole or partly)	Microgrid Operator has send flexible resource bids for Aggregator	Bid is accepted in the flexibility markets (in whole or partly) and new flexibility optimizations are created based on updated situation

Steps – Normal Sequence

Scenario Name :	*PS1: Normal sequence*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Require-ments ID***
Before the triggering event (Step 1), bid is created and sent to Aggregator as follows (Yellow part of sequence diagram):						
0	Data request Periodically (before deadline for bid submission)	MGMS.DA requests flexible capacity information from its own EMS (logic for determining flexible capacity is out of the scope of HEILA, i.e. every actor does it itself)	CEMS	MGMS.DA	Flexible capacity of CEMS (amount, time)	
0	Forecast update Periodically	Service Provider sends weather forecasts to MGMS.DA	SP	MGMS.DA	Weather forecast	
0b	Data transfer	MGMS.DA transfers the data to MGMS.DM	MGMS.DA	MGMS.DM	Flexible capacity of CEMS (amount, time), weather forecast	
0c	Data is transfered to MGMS.DM	MGMS.DM passes the data to MGMS.TS	MGMS.DM	MGMS.TS	Flexible capacity of CEMS (amount, time), weather forecast	
0d	Data is transfered to MGMS.TS	MGMS.TS makes local (microgrid level) optimization. As an output, amount of flexible capacity is determined.	MGMS.TS	MGMS.TS		
0e	Flexible capacity is determined	MGMS.TS passes the information to MGMS.DT for transmission	MGMS.TS	MGMS.DT	Flexible capacity of Microgrid (amount, time)	

0f	Information about Flexible capacity is ready to be sent to Aggregator	MGMS.DT sends information about the flexible capacity to Aggregator	MGMS.DT	AMS.DA	Flexible capacity of Microgrid (amount, time)
0g	Bid or part of it has been accepted on the market	MO (MGMS.DA) receives notification from Aggregator of accepted bid	AMS.DT	MGMS.DA	Regulation information (up- or down regulation, amount (MW), time period, price, location)
0h	MGMS.DA has received the accepted bid	MGMS.DA transfers the notification to MGMS.DM	MGMS.DA	MGMS.DM	Regulation information (up- or down regulation, amount (MW), time period, price, location)
0i	MGMS.DM has received the accepted bid	MGMS.DM reads the notification and generates separate notifications to be sent for proper CEMS's via MGMS.DT	MGMS.DM	MGMS.DT	Regulation information (up- or down regulation, amount (MW), time period, price, location)
0j	Accepted bid is separeted into single notifications concerning separate CEMSs	MGMS.DT sends the notifications to proper CEMS's	MGMS.DT	CEMS	Regulation information (up- or down regulation, amount (MW), time period, price, location)
Conditional Re-Profiling (CRP) bid is accepted on the market (Blue part of sequence diagram):					
1	Notification	MO receives activation notification from Aggregator of accepted bid	AMS.DT	MGMS.DA	Control command
2	MGMS.DA has received notification of accepted bid	MGMS.DA sends the notification to MGMS.DM	MGMS.DA	MGMS.DM	Control command
3	Notification is send to MGMS.DM	MGMS.DM sends the notification to MGMS.DT for distribution to proper CEMSs	MGMS.DM	MGMS.DT	Control command
5	Notification is send to MGMS.DT	MGMS.DT distributes the control commands to CEMSs based on the activation notifications.	MGMS.DT	CEMS	Control command
6	CEMS has executed the regulation	CEMS sends verification of regulation to MGMS.DA	CEMS	MGMS.DA	Verification
7	MGMS.DA has received verification of regulation	MGMS.DA sends verification of regulation to MGMS.DM	MGMS.DA	MGMS.DM	Verification
8	MGMS.DM has received verification of regulation	MGMS.DM creates summary report of verification notifications and sends it to MGMS.DT	MGMS.DM	MGMS.DT	Verification
9	MGMS.DT has received verification of regulation	MGMS.DT sends the summary report of verifications to AMS.DA	MGMS.DT	AMS.DA	Verification

APPENDIX 3: SIGNAL TAGS IN MULTIPOWER

***Table 11. Signal mapping tags for measurements and status of JK_T_KK_TL3 feeder. Other REF615s tags are done in the same way* [21].**

Tag	Description
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotW.instMag	Total real power
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotW.t	Total real power timestamp
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotW.q	Total real power quality indicator
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotVA.instMag	Total apparent power
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotVA.t	Total apparent power timestamp
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotVA.q	Total apparent power quality indicator
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotVAr.instMag	Total reactive power
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotVAr.t	Total reactive power timestamp
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotVAr.q	Total reactive power quality indicator
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotPF.instMag	Total power factor
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotPF.t	Total power factor timestamp
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_TotPF.q	Total power factor quality indicator
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_A.phsA.cVal	Phase A current
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_A.phsA.t	Phase A current timestamp
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_A.phsA.q	Phase A current quality indicator
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_A.phsB.cVal	Phase B current
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_A.phsB.t	Phase B current timestamp
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_A.phsB.q	Phase B current quality indicator
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_A.phsC.cVal	Phase C current
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_A.phsC.t	Phase C current timestamp
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_A.phsC.q	Phase C current quality indicator
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_PhV.phsA.cVal	Phase A phase voltage
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_PhV.phsA.t	Phase A phase voltage timestamp
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_PhV.phsA.q	Phase A phase voltage quality indicator
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_PhV.phsB.cVal	Phase B phase voltage
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_PhV.phsB.t	Phase B phase voltage timestamp
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_PhV.phsB.q	Phase B phase voltage quality indicator
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_PhV.phsC.cVal	Phase C phase voltage

VTT:Protection_JK-T.KK-TL3.REF615:M_EA_PhV.phsC.t	Phase C phase voltage timestamp
VTT:Protection_JK-T.KK-TL3.REF615:M_EA_PhV.phsC.q	Phase C phase voltage quality indicator
VTT:Protection_JK-T.KK-TL3.REF615:C_EA_Pos.stVal	Circuit breaker position (10=closed, 01=open)
VTT:Protection_JK-T.KK-TL3.REF615:C_EA_Pos.t	Circuit breaker position timestamp

APPENDIX 4: INTERFACES, DATABASES AND FUNCTIONS OF DMS, CA AND MGCC

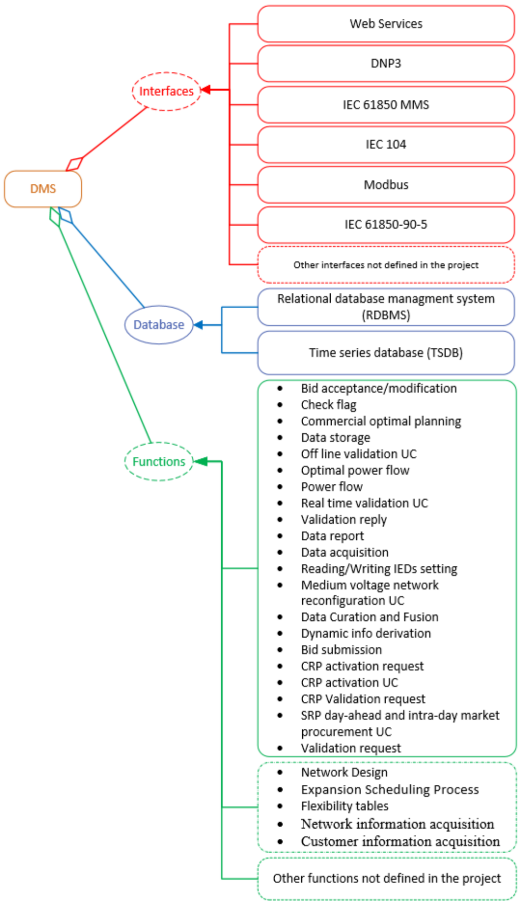
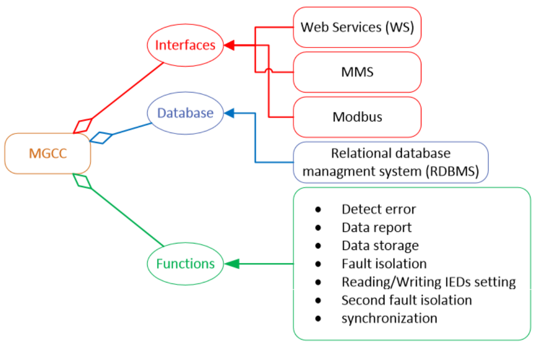


Figure 59. IDE4L DMS interfaces, databases and functions [35].



b) MicroGrid Central Controller

a) Commercial Aggregator

Figure 60. IDE4L CA and MGCC interfaces, databases and functions [35].

APPENDIX 5: IEC 61850 CDCS, CIRCUIT BREAKER LOGICAL NODE, COMMON DATA CLASS *DPC AND MAPPING OF CDCS TO ASDU TYPES*

Table 12. Specific Common Data Classes [85].

Information
Status: Single point status (SPS) Double point status (DPS) Integer status (INS) Protection activation information (ACT) Directional protection activation information (ACD) Security violation counting (SEC) Binary counter reading (BCR)
Measurand: Measured value (MV) Complex measured value (CMV) Sampled value (SAV) Phase to ground/neutral related measured values of a three-phase system (WYE) Phase to phase related measured values of a three-phase system (DEL) Sequence (SEQ)
Controllable status: Controllable single point (SPC) Controllable double point (DPC) Binary controlled step position information (BSC) Integer controlled step position information (ISC) Controllable analogue process value (APC)
Controllable analogue: Single point setting (SPG) Integer status setting (ING)
Description: Device name plate (DPL) Logical node name plate (LPL)
Settings
Analogue: Analogue setting (ASG) Setting curve (CURVE)

Table 13. Circuit breaker logical node, adapted from [86].

XCBR class			
Data object name	**Common data class**	**Explanation**	**M/O/C**
LNName		The name is composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2	

Data objects			
Descriptions			
EEName	DPL	External equipment name plate	O
Status information			
EEHealth	ENS	External equipment health	O
LocKey	SPS	Local or remote key	O
Loc	SPS	Local control behavior	M
OpCnt	INS	Operation counter	M
CBOpCap	ENS	Circuit breaker operating capability	O
POWCap	ENS	Point on wave switching capability	O
MaxOpCap	INS	Circuit breaker operating capability when fully charged	O
Dsc	SPS	Discrepancy	O
Measured and metered values			
SumSwARs	BCR	Sum of switched amperes, resettable	O
Controls			
LocSta	SPC	Switching authority at station level	O
Pos	DPC	Switch position	M
BlkOpn	SPC	Block opening	M
BlkCls	SPC	Block closing	M
ChaMotEna	SPC	Charger motor enabled	O
Settings			
CBTmms	ING	Closing time of breaker	O
Abbreviations: For data object semantics, see IEC 61850-7-4 Table 10. M=Mandatory, O=Optional, C=Conditional			

Table 14. Common Data Class DPC, adapted from [85].

DPC class					
Data attribute name	**Type**	**FC**	**TrgOp**	**Value/Value range**	**M/O/C**
Data name	Inherited from GenDataObject Class of from GenSubDataObject Class (IEC 61850-7-2)				
DataAttribute					
status and control mirror					
origin	Originator	ST			AC_CO_O
ctlNum	INT8U	ST		0…255	AC_CO_O
stVal	CODED ENUM	ST	dchg	intermedi-ate|off|on|bad-state	M
q	Quality	ST	qchg		M
t	TimeStamp	ST			M
stSeld	BOOLEAN	ST	dchg		O
opRcvd	BOOLEAN	OR	dchg		O
opOk	BOOLEAN	OR	dchg		O
tOpOk	TimeStamp	OR			O
substitution and blocked					
subEna	BOOLEAN	SV			PICS_SUBST

subVal	CODED ENUM	SV		intermedi-ate|off|on|bad-state	PICS_SUBST
subQ	Quality	SV			PICS_SUBST
subID	VISIBLE STRING64	SV			PICS_SUBST
blkEna	BOOLEAN	BL			O
configuration, description and extension					
pulseConfig	PulseConfig	CF	dchg		AC_CO_O
ctlModel	CtlModels	CF	dchg		M
sboTimeout	INT32U	CF	dchg		AC_CO_O
sboClass	SboClasses	CF	dchg		AC_CO_O
operTimeout	INT32U	CF	dchg		AC_CO_O
d	VISIBLE STRING255	DC		Text	O
dU	UNICODE STRING255	DC			O
cdcNS	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M
Services					
Defined in different table (IEC 61850-7-3)					
Abbreviations and conditions for presence of an attribute: For data attribute and functional constraint semantics, see IEC-61850-7-3 tables 64 and B.1, respectively. FC=Functional constraint TrgOp=Trigger option ST=Status information OR=Operate received SV=Substitution BL=Blocking CF=Configuration DC=Description EX=Extended definition dchg=trigger option for data-change qchg=trigger option for quality-change AC_CO_O=If the controllable status class supports control, this attribute is available and an optional attribute PICS_SUBST=Attribute is mandatory, if substitution is supported (see IEC-61850-7-2), other-wise forbidden AC_DLNDA_M=The attribute shall be present, if CDC name space of this data deviates from the CDC AC_DLN_M=The attribute shall be present, if the data name space of this data deviates from the data name space lnNs of the logical node, it doesn't exist or ldNs of the logical device in which the data is contained.					

Table 15. Mapping of CDCs to ASDU types, adapted from [47].

CDC (Attribute data types)	**ASDU Type**
Single point status (SPS)	monitor direction (status) TI<30> as event TI<1> as part of GI
Double point status (DPS)	monitor direction (status) TI<31> as event TI<3> as part of GI
Integer status (INS)	monitor direction (status) TI<35> or TI<33> as event TI<11> or TI<7> or TI<1> as part of GI
Protection activation information (ACT)	monitor direction (status) TI<39> as event or TI<30> as event TI<1> as part of GI
Directional protection activation information (ACD)	monitor direction (status) TI<40> as event or TI<30> as event TI<1> as part of GI
Security violation counting (SEC)	monitor direction (status) TI<37> as event or as part of CI
Binary counter reading (BCR)	monitor direction (status) TI<37> as event or as part of CI
Measured value (MV)	monitor direction (status) TI<36> or TI<35> as event TI<13> or TI<11> as part of GI
Complex measured value (CMV)	monitor direction (status) TI<36> or TI<35> as event TI<13> or TI<11> as part of GI
Phase to ground/neutral related measured values of a three-phase system (WYE)	monitor direction (status) via CMV to TI<36> or TI<35> as event TI<13> or TI<11> as part of GI
Phase to phase related measured values of a three-phase system (DEL)	monitor direction (status) via CMV to TI<36> or TI<35> as event TI<13> or TI<11> as part of GI
Sequence (SEQ)	monitor direction (status) via CMV to TI<36> or TI<35> as event TI<13> or TI<11> as part of GI
Controllable single point (SPC)	monitor direction (status) TI<30> as event TI<1> as part of GI control direction (command) TI<45> (without time) or TI<58> (with time tag)
Controllable double point (DPC)	monitor direction (status) TI<31> as event TI<3> as part of GI

	control direction (command) TI<46> (without time) or TI<59> (with time tag)
Binary controlled step position information (BSC)	monitor direction (status) TI<32> as event TI<5> as part of GI control direction (command) TI<47> (without time) or TI<60> (with time tag)
Integer controlled step position information (ISC)	monitor direction (status) TI<32> as event TI<5> as part of GI control direction (command) TI<49> (without time) or TI<62> (with time tag)
Controllable analogue process value (APC)	monitor direction (status) TI<36> as event TI<13> as part of GI control direction (setpoint) TI<50> (without time) or TI<63> (with time tag)
Single point setting (SPG)	control direction (command) TI<45> (without time) or TI<58> (with time tag)
Integer status setting (ING)	control direction (setpoint) TI<49> (without time) or TI<62> (with time tag)
Analogue setting (ASG)	control direction (setpoint) TI<50> (without time) or TI<63> (with time tag)
Abbreviations: TI=Type Identification GI=General Interrogation or station interrogation CI=Counter interrogation ASDU TI<101>	
NOTE: The mappings include the timestamp if sent as an event. All GI and CI data exclude timestamp.	

Table 16. Common Data Class DPS IEC 60870-5-104 mapping, adapted from [47]**.**

<table>
<tr><th colspan="2">CDC class</th><th colspan="2">IEC-60870-5-101 or -104 mapping</th></tr>
<tr><td colspan="2">DPS</td><td colspan="2">TI<31></td></tr>
<tr><td>Attribute name</td><td>Attribute type</td><td>Information element</td><td>IEC 60870-5-101 or -104 object group mapping</td></tr>
<tr><td>stVal</td><td>CODED ENUM</td><td>DIQ</td><td>DPI
<0> intermediate state = intermediate-state
<1> determined state OFF = OFF
<2> determined state ON = ON
<3> indeterminate = bad.state</td></tr>
<tr><td>q</td><td>Quality</td><td></td><td>validity -> IV good | invalid | -> valid | in-valid
questionable -> NT
source -> SB substituted -> substituted
operatorBlocked -> BL blocked -> blocked</td></tr>
</table>

t	TimeStamp		Seven octet binary time, CP56Time2a - Time of occurrence of dchg or qchg

Table 17. Common Data Class DPC IEC 60870-5-104 mapping, adapted from [47].

CDC class		**IEC-60870-5-101 or -104 mapping**	
DPC		TI<46> (without time) or TI<59> (with time tag)	
Attribute name	**Attribute type**	**Infor-mation ele-ment**	**IEC-60870-5-101 or -104 object group mapping**
ctlVal	BOOLEAN	DCO	DCS (Double command state) <0> not permitted <1> OFF = off (FALSE) <2> ON = on (TRUE) <3> not permitted simple DPC -> QU <0> no additional definition other QU values may be used in range of <9> to <15> and <16> to <31>, see IEC 61850-80-1 Clause 8.8 for details IEC 60870-5-101 and -104 support following IEC-61850 Control Models (ctlModel): direct control with normal security direct control with enhanced security S/E <0> = direct control SBO control with enhanced security S/E <1> = select and execute, see IEC 61850-80-1 subclause 8.8 for details
origin.orIdent	OCTET STRING64	COT	Originator Address=UI8[9..16]<0..255> <0> = default <1..255> = number of originator address The number of originator address shall be mapped to attribute orIdent (OCTET STRING64). Only one octet can be used.
origin.orCat	ENUMERATED	COT	Cause=UI6[1..6]<0..63> Valid for parameter for control services, or if FC=CO Valid for FC=ST:

			not supported <-> not used <0> remote control <-> return information caused by remote command <11> automatic-remote -> return information caused by remote command <11> bay control <-> return information caused by local command <12> station control, automatic bay, automatic station -> return information caused by local command <12> process <-> spontaneous <3> maintenance <-> spontaneous <3>
Abbreviations: COT=Cause of transmission QU=Qualifier of command S/E=Select/Execute SBO=Select before operate			

APPENDIX 6: MQTT CONTROL PACKET TYPES AND QOS PROTOCOL FLOW

Table 18. MQTT control packet types, adapted from [72].

Name	Direction of flow	Description
CONNECT	Client to Server	Client request to connect to Server
CONNACK	Server to Client	Connect acknowledgement
PUBLISH	Client to Server or Server to Client	Publish acknowledgment
PUBACK	Client to Server or Server to Client	Publish acknowledgment
PUBREC	Client to Server or Server to Client	Publish received (assured delivery part 1)
PUBREL	Client to Server or Server to Client	Publish release (assured delivery part 2)
PUBCOMP	Client to Server or Server to Client	Publish complete (assured delivery part 3)
SUBSCRIBE	Client to Server	Client subscribe request
SUBACK	Server to Client	Subscribe acknowledgment
UNSUBSCRIBE	Client to Server	Unsubscribe request
UNSUBACK	Server to Client	Unsubscribe acknowledgment
PINGREQ	Client to Server	PING request
PINGRESP	Server to Client	PING response
DISCONNECT	Client to Server	Client is disconnecting

Table 19. QoS protocol flow diagram, non-normative example, adapted from [72].

Sender Action, QoS 0	**Control Packet**	**Receiver Action**
PUBLISH QoS 0, DUP=0		
	→	
		Deliver Application Message to appropriate onward recipient(s)
Sender Action, QoS 1	**Control Packet**	**Receiver Action**
Store message		
Send PUBLISH QoS 1, DUP=0, <Packet Identifier>	→	
		Initiate onward delivery of the Application Message
	←	Send PUBACK <Packet Identifier>
Discard message		
Sender Action, QoS 2	**Control Packet**	**Receiver Action**

Store message		
PUBLISH QoS 2, DUP=0, <Packet Identifier>		
	→	
		Method A, Store message or Method B, Store <Packet Identifier> then Initiate on-ward delivery of the Application Message
		Send PUBCOMP <Packet Identifier>
	←	
Discard stored state		

APPENDIX 7: USE CASE SEQUENCE DIAGRAMS

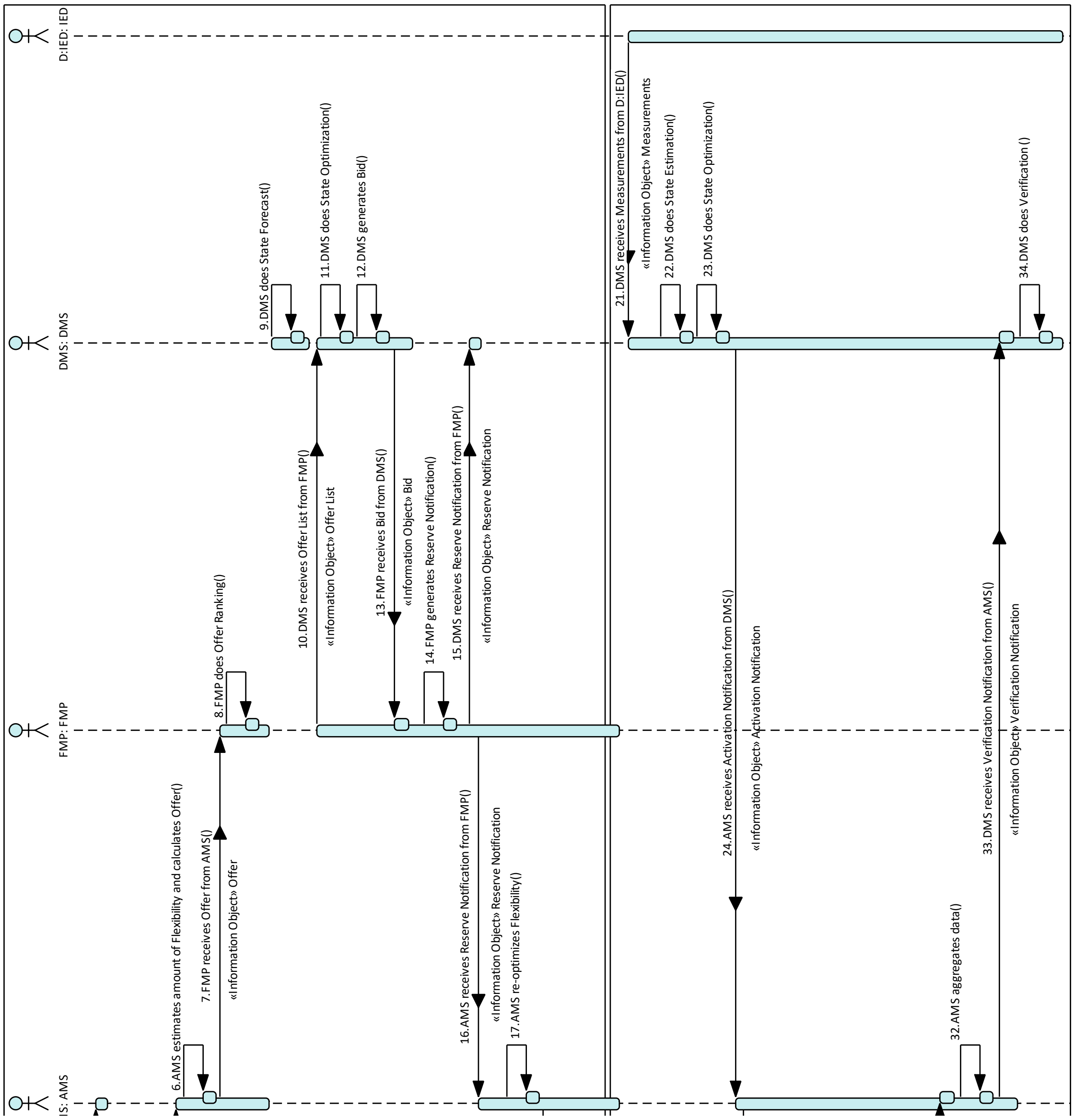


Figure 61. DSO Flexibility sequence diagrams part 1.

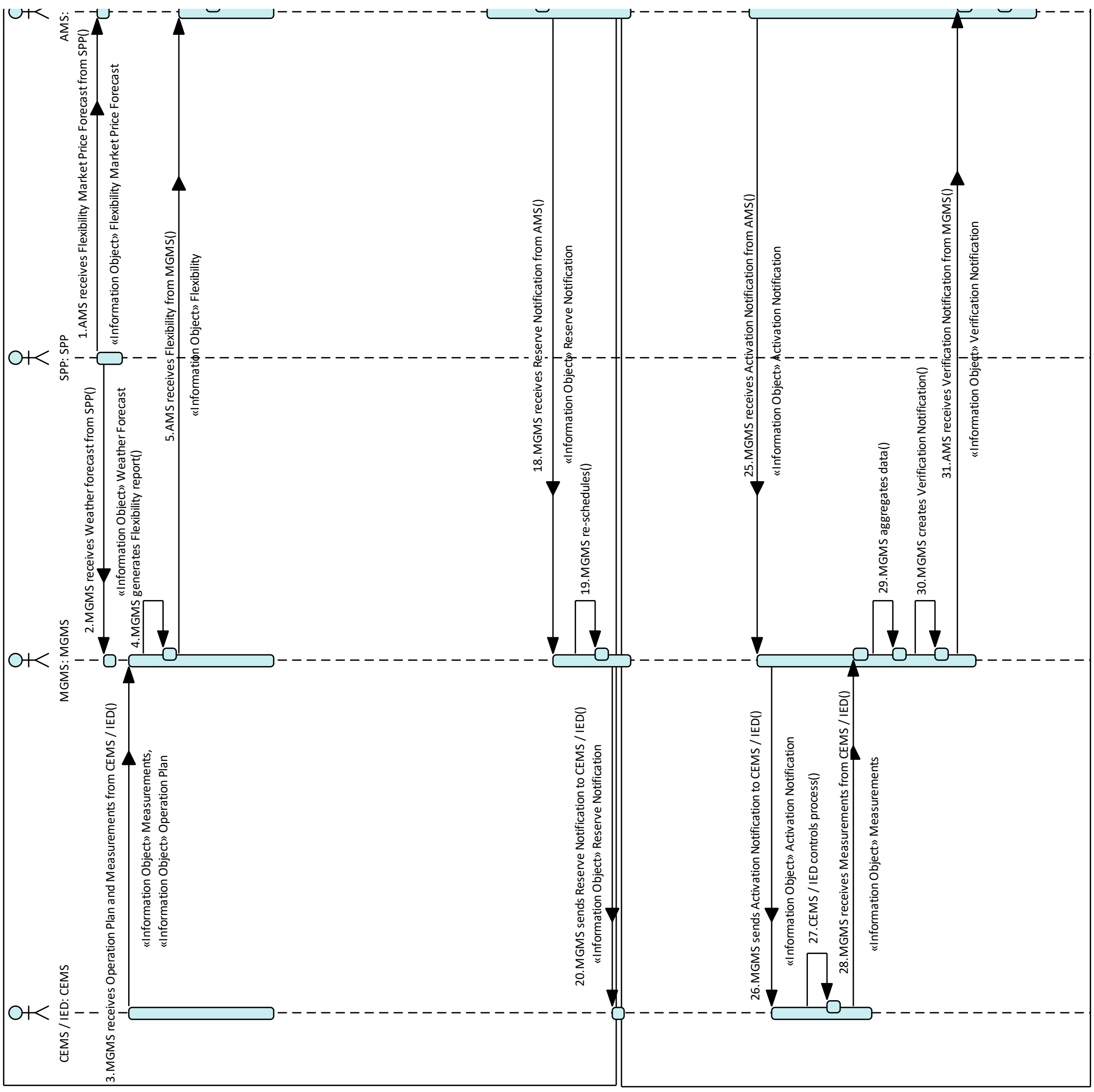


Figure 62. DSO Flexibility sequence diagrams part 2.

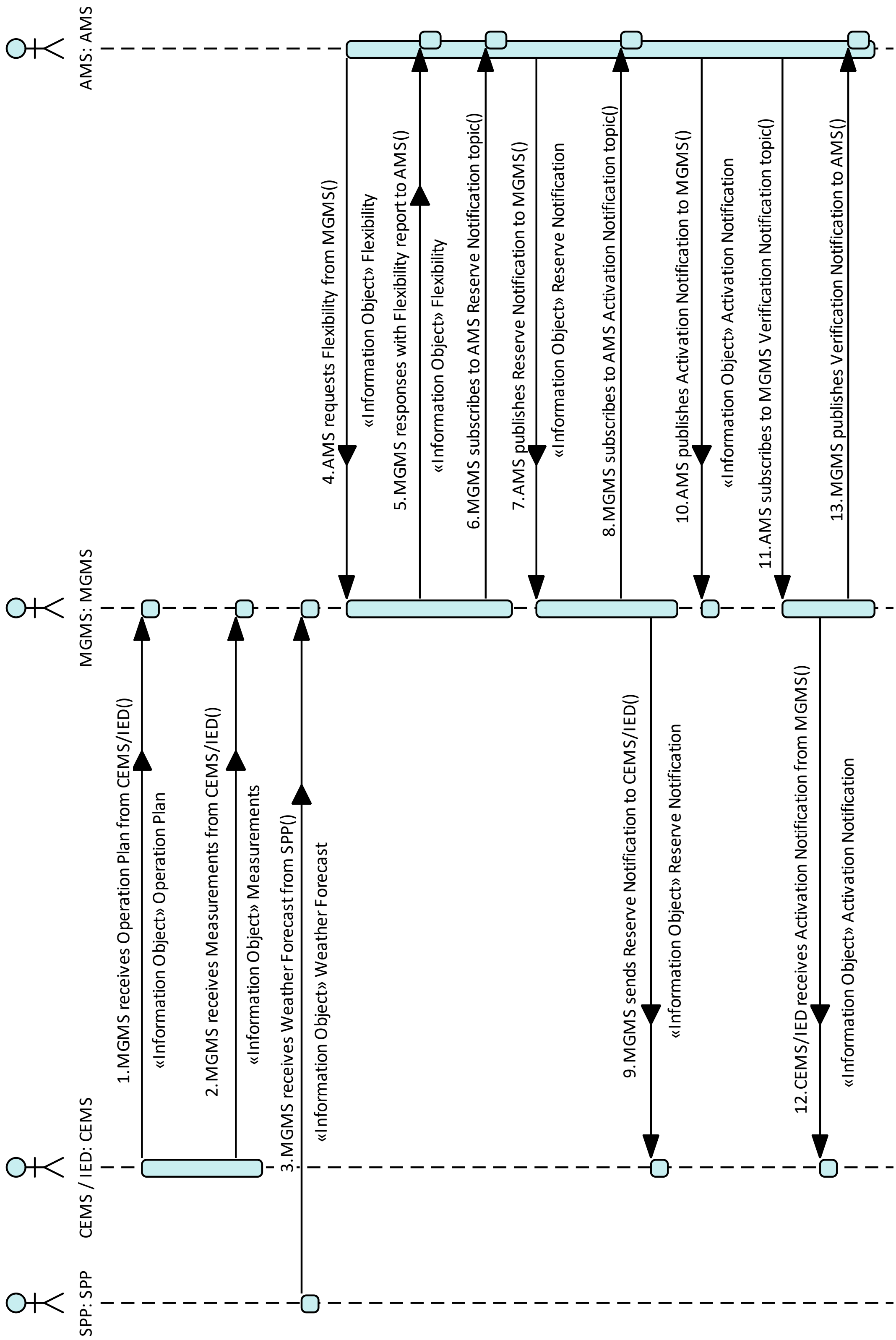


Figure 63. Microgrid Monitoring sequence diagram.

APPENDIX 8: DELAY TEST RESULTS

Table 20. Delay test results for monitor direction.

Timestamp 1	Timestamp 2	Delay (ms)
Feeder JK-T.KK-TL3, JK-T.KK-TRB or JK-T.RK-TRB phase voltage		
REF615	MGMS Redis database	
09:02:48.573	09:02:48.999	426
09:02:48.573	09:02:49.069	496
09:02:48.573	09:02:49.161	588
09:03:04.487	09:03:04.975	488
09:03:04.487	09:03:05.174	687
09:03:04.487	09:03:05.351	864
09:32:15.246	09:32:15.570	324
09:32:15.246	09:32:15.616	370
09:32:15.246	09:32:15.626	380
09:33:03.391	09:33:03.597	206
Flexibility IO with server - client		
MGMS Redis database	AMS Redis database	
07:04:09.958	07:04:10.009	45
07:04:21.506	07:04:21.551	47
07:04:23.540	07:04:23.587	46
07:04:25.104	07:04:25.150	47
07:04:26.500	07:04:26.546	47
07:04:28.008	07:04:28.055	46
07:04:29.302	07:04:29.349	46
07:04:30.592	07:04:30.638	47
07:04:31.869	07:04:31.916	45
07:04:33.050	07:04:33.095	51
Flexibility IO with publisher - subscriber		
MGMS Redis database	AMS Redis database	
07:41:32.188	07:41:32.295	107
07:41:37.208	07:41:37.257	49
07:41:42.214	07:41:42.251	37
07:41:47.220	07:41:47.301	81
07:41:52.227	07:41:52.275	48
07:41:57.233	07:41:57.274	41
07:42:02.239	07:42:02.281	42
07:42:07.246	07:42:07.283	37
07:42:12.252	07:42:12.289	37
07:42:17.259	07:42:17.296	37

Table 21. Delay test results for control direction.

Timestamp 1	**Timestamp 2**	**Delay (ms)**
ActivationNotification IO with publisher - subscriber		
AMS Redis database	MGMS Redis database	
12:41:39.092	12:41:39.130	38
12:42:49.184	12:42:49.220	36
12:43:47.706	12:43:47.740	34
12:44:32.490	12:44:32.527	37
12:46:45.528	12:46:45.564	36
12:47:22.249	12:47:22.284	35
12:48:53.509	12:48:53.545	36
12:49:39.478	12:49:39.515	37
12:50:42.494	12:50:42.530	36
12:51:51.722	12:51:51.760	38
Controllable double point, DPC, IEC 60870-5-104 mapping TI=46. REF615 circuit breaker status (open) and timestamp were gathered from COM600.		
MGMS Redis database	REF615	
12:41:39.130	12:41:39.734	604
12:42:49.220	12:42:49.824	604
12:43:47.740	12:43:48.247	545
12:44:32.527	12:44:33.117	590
12:46:45.564	12:46:46.185	621
12:47:22.284	12:47:22.880	596
12:48:53.545	12:48:54.130	585
12:49:39.515	12:49:40.056	541
12:50:42.530	12:50:43.125	595
12:51:51.760	12:51:52.322	562